Sarah Gaichas – Draft document on Sustainability and Ecosystem Management – This is part of Chapter 1 of a Ph.D. Dissertation in SAFS, University of Washington

"Paradise has been lost, not to sin, but to science."
--Stuart Kauffman (1995)

"Science has failed our world. Science has failed our mother earth."
--System of a Down (2001)

Introduction

This chapter lays the foundation for the ecosystem modeling experiments and management recommendations in the remainder of the thesis. The material for the foundation is history, and there are two components to this historical foundation: conceptual history and exploitative history. In the first section, I review the concepts of "ecosystem" and "sustainability" as they developed in the scientific literature and in cultural discourse. The purpose of this review is to illuminate the interaction of ecosystem science and mathematical modeling with resource management and in larger society, and to suggest constructive ways of moving forward with practical ecosystem-based fishery management based on a common understanding of "ecosystem sustainability" which makes use of our mathematical, scientific, and cultural sophistication. In the second section, I chronologically review the history of large scale commercial exploitation in the Gulf of Alaska and the concurrent (or subsequent) development of scientific understanding of the physics and biology of the system. The review of the Gulf of Alaska's exploitation history serves three purposes. First, it provides a specific, close to home example of the development of cultural attitudes towards resource use and sustainability outlined in the first section. Second, and perhaps more importantly, the historical review combines the histories of components that we currently study, manage, and understand in separate compartments (e.g. salmon vs. marine mammals), so that we might begin to understand the history of Gulf of Alaska ecosystem in a different light: as an integrated, interacting, evolving, complex adaptive system. Finally, the exploitation history establishes today's conditions in both the ecosystem and in the management system—we need to know where we have been to understand where we are now, and to plan where we might go next.

I. A context for ecosystem based management: developing concepts of ecosystems and sustainability

In this section, I review two concepts that form the foundation of ecosystem based fishery management: the concepts of "ecosystem" and of "sustainability". Both ideas have developed relatively recently in scientific and cultural discourse, and each concept is linked with the exploitation of natural resources, and with mathematical modeling. Ecosystems have been viewed from one extreme as purely chaotic, untamed nature, and from another extreme as purely physical systems with predictable equilibrium states. A developing concept of ecosystems as "complex adaptive systems" lies between these extreme concepts; the ecosystem as complex adaptive system has behavior which is recognizably patterned and yet not fully predictable. Sustainability has also been defined and redefined—culturally, mathematically, and legally—as humans have exploited and often depleted desirable natural resources. Fisheries theory and modeling has provided some of the most important conceptual advances along the way, but must re-examine some of the conceptual shackles which have been unconsciously adapted. In my view, the most powerful union of "ecosystem" and "sustainability" combines understanding the defining characteristics of complex adaptive systems with the objective of identifying and sustaining healthy relationships within and between the interconnected spheres of ecosystem, economy, and society.

The ecosystem: from a predictable equilibrium to a complex adaptive system

An ecosystem is generally defined as a community of living organisms interacting with each other and their physical environment in a specific place (ref any biology text). However, the ecosystem as a scientific concept has evolved considerably since its first use in the literature by Tansley (1935) (Bocking 1994). Tansley sought to clarify some terminology for the study of successional change in vegetation, and to assert that assemblages of plants and animals did not represent "organisms" or "complex organisms" as some had proposed (Clements 1916, 1934 and Phillips 1931, 1934, 1935 as referenced in Tansley 1935). Tansley's ecosystem concept unified the physical and climatic environment with the biological assemblage, and also defined an expected type of system behavior:

> "The fundamental concept appropriate to the biome considered together with all the effective inorganic factors of its environment is the *ecosystem*, which is a particular category among the physical systems that make up the universe. In an ecosystem the organisms and the inorganic factors alike are *components* which are in relatively stable dynamic equilibrium. Succession and development are instances of the universal processes tending towards the creation of such equilibrated systems."

In this characterization, the fields of physics and biology are united, systems progress towards idealized equilibrium states, and universality is invoked; themes repeated throughout the scientific development of the ecosystem concept. Tansley's ecosystem concept emphasizes climax communities: "The 'climax' represents the highest stage of integration and the nearest approach to perfect dynamic equilibrium that can be attained in a system developed under the given conditions and with the available components." In his view, non-climax systems are damaged or otherwise compromised, but removing the compromising agent allows progress back towards the (ideal) climactic equilibrium. Interestingly, this is how certain mathematical models of systems behave, although Tansley did not introduce mathematical modeling along with the ecosystem concept.

Tansley was especially critical of the idea (espoused by Phillips 1935) that a biological system might have characteristics or behavior at the system level that was unpredictable when only the characteristics or behavior of the components were considered. "Unpredictable by us with out present knowledge, yes; but *theoretically* unpredictable, surely not." To solidify the point, Tansley compares a biological system and a human-engineered system: "When an inventor makes a new machine, he is just as certainly making a new entity, but he can predict with accuracy what it will be and what it will do, because within the limits of his purpose he does understand the whole of the relevant properties of his materials and knows what their interactions will be, given a particular set of spatial relations which he arranges (Tansley 1935)." The idea of nature-as-controllable-machine was part of the cultural landscape at the time (Worster 1993; see below), and apparently hindered acceptance of the now better described ideas of emergent properties and complex systems behavior (see below).

The ecosystem concept was developed significantly when Lindeman (1942) introduced energy transfer between trophic levels as the primary organizing feature for the study of ecosystems (Bocking 1994). Lindeman challenged the arbitrary division between living and non-living components of systems from the trophic perspective, therefore emphasizing mechanical over "natural" properties (Bocking 1994). He placed ecological succession and climax within in an energetic context, suggesting that climax systems were generally most productive, and that energy transfer also becomes more efficient as succession towards climax proceeds. Importantly, he provided rudimentary quantitative methods for estimating energy transfer, transfer efficiency, and productivity, which laid the foundations for mathematical analysis of ecosystems (Hutchinson 1942). These quantitative methods which outlined energy transfer in terms of primary and secondary production rates, predator consumption rates, respiration rates, and growth rates are at the basis of mathematical food web models today. Energy transfer within ecosystems became the sole focus half a century later for H.T. Odum, who formally connected the study of ecological processes with thermodynamic principles and in the process further extended the metaphor of ecosystems as engineered systems, specifically electronic circuits (Odum 1994).

Lindeman's 1942 paper represents an initial application of mathematical methodology to ecological theory, which was developed further in the applied realm of fisheries population modeling. The concept (from Tansley, Lindeman and other ecologists) of potentially quantifiable, predictable, machine-like ecosystems tending toward equilibrium over time meshes beautifully with the analytical methods of differential calculus. With the mathematical tools in place (since ref), models of biological systems were soon built to demonstrate the possibility of manipulating the system towards maximum efficiency and productivity for human exploitation—but the systems were viewed at the population level, not the ecosystem level, and the populations were fish populations, not plant or even lake communities (e.g., Baranov 1918, Thompson and Bell 1934). Employing terminology reflecting the ecosystem concept, Beverton and Holt (1957) characterized the fish population as "a self-maintaining *open system*, exchanging materials with the environment and usually tending towards a steady state." Marine fisheries management needs precipitated the birth of quantitative population modeling and scientifically supported optimal exploitation:

> "It became necessary to predict the effects of changes in the amount of fishing, in mesh of nets, of variations in growth rate due to thinning out the stocks by fishing and of variations in the rates of reproduction and survival: in general, to determine what effects are of a major order and what minor, and to estimate, for the industry and for governments, the magnitude of the benefits that can be achieved by conservative fishing." (Graham 1954, in the preface to Beverton and Holt 1957).

Quantitative methods for calculating "the ideal level of exploitation" to produce optimal yield in fisheries were introduced in response to this need by Beverton and Holt (1957). The lesson learned by observing the decline and subsequent rebound of stocks in the North Sea (which had been temporarily unexploited during World War II) was that excessive fishing had reduced the productivity of the populations, but that changing fishing mortality could increase production again, and that manipulation of the population parameters via controlled fishing mortality could be used to advantage. Further, in contrast to the purely academic development of the ecosystem concept described above, Beverton and Holt (1957) considered the relationship between biological systems and socio-economic considerations essential. Prediction was no longer conceptual, it was necessary for optimal management. Emphasis on a tendency towards equilibrium became dependence; we were collectively banking on models the authors themselves cautioned "were old-fashioned before they were developed, since they are in nearly all cases 'deterministic' (Beverton and Holt 1957)."

Beverton and Holt's work added a dimension to the ecosystem-as-controllable-machine concept: mathematical modeling for optimal control of the production of economically important resources. While this represented a positive outcome of human interaction with ecosystems as mediated by scientific/economic theory, by the 1960's negative effects of human scientific/economic control activities on ecosystems were also becoming apparent, such as the ecological effects of pesticides (Carson 1962). Even as more awareness of the potential for human-induced global (negative) change appeared in the ecosystem concept, the mechanistic theory and associated models remained basically unchanged. By the late 1960s, ecological succession was still described as directional and predictable, biologically controlled (but physically constrained), and culminating in a stable state with maximal "homeostasis" (Odum 1969). Although the now familiar ideas of progression to an idealized stable state were intact, E.P. Odum (H.T Odum's elder brother) presented his ecosystem concept as potentially in conflict with the human desire for maximum production (yield). He also suggested the importance of maintaining a mosaic of ecosystem types from young and productive (agriculture) to mature and stable (nature preserve) with compromise systems in between (eg. estuaries and other naturally periodically disturbed systems which are stable in a "non-climax" state, and urban-industrial systems that we give up on entirely). Mathematical modeling is now central to this process. Odum's (1969) ambitious proposal that we quantify how much of each ecosystem type is necessary to maintain humans and the biosphere (in order to limit urban growth and further environmental degradation) mirrors the optimism expressed by Tansley (1935) that ecosystems would eventually be as understandable (and by extension controllable) as human made machines. However, Odum (1969) conceded that we required more time to study ecosystems and make better models.

Unfortunately, time was short. By late 1970s, considerable disillusion with ecosystem modeling capability had overwhelmed the scientific community (Bocking 1994). The general consensus seemed to be that the models were not sufficiently predictive, so we should study only the system components of management interest, rather than the system itself. At the time, Odum (1977) expressed frustration with purely reductionist scientific approaches, and re-introduced the idea that the ecosystem itself should be studied in addition to its components, because “as components, or subsets, are combined to produce larger functional wholes, new properties emerge that were not present or not evident at the next level below.” However, fisheries science was not ready for this idea, and remained obstinately reductionistic for at least the next 16 years, as evidenced in Hilborn and Walters (1993). In this mathematically sophisticated and widely used fisheries stock assessment textbook, these influential fisheries scientists succinctly discredited multispecies, food web, and trophic level models for use in management: “We believe the food web modeling approach is hopeless as an aid to formulating management advice; the number of parameters and assumptions required are enormous.” The recommended alternative to placing fisheries within an ecosystem context was to “Ignore biological interaction. This is a very viable alternative to spending a lot of time and effort trying to understand biological interaction, and represents a sort of default assumption. Even though it may represent a ‘stick your head in the sand’ approach, it may often prove to be the best thing to do (Hilborn and Walters 1993).”

The Hilborn and Walters “ostrich” approach to ecological modeling is no longer recommended even by its original proponents, in part because advances in computational capabilities have rendered some simplifying assumptions unnecessary, and in part because it didn’t often prove to be the best thing to do from a resource management standpoint. Willful blindness to biological interaction is not acceptable to an ecologically savvy fishing industry, to the conservation community, or to the general public, and management exists to serve these constituents, not ignore them. But what to do, knowing that the complexity of ecosystem interactions is very real, and still largely beyond scientific description?

One course of action is to embrace the complexity inherent in ecosystems. Developments in the fields of mathematics and physics—the “discovery” of mathematical chaos and concurrent development of the theory of complex adaptive systems—have recently been incorporated into the ecosystem concept (Levin 1998, 2002, and more refs). Mathematical chaos is the apparently “random” behavior observed in deterministic nonlinear dynamical systems under certain conditions, which involve the governing equations interacting with specific parameter sets (my synthesis from refs). Chaos has been described as “the [20th] century’s third great revolution in the physical sciences,” after relativity and quantum mechanics (Gleick, 1987). Two of the most famous examples of chaos arise from models relevant to populations and ecosystems: the logistic equation and the Lotka-Volterra predator-prey equations (May 1987). It seems clear that the conditions leading to mathematical chaos in these equations are found in natural populations with growth rates more like bacteria microbes than fish (May 1987, Hilborn ref), but that is not the point. The conceptual breakthrough of mathematical chaos is that it demonstrates the *theoretically* unpredictable nature of even simple engineered systems: deterministic equations. We cannot predict where a chaotic system will be at a given time in the future without knowing the starting conditions to an infinite number of decimal places. The measurement error inherent in reality ensures that these systems are unpredictable. Thus, chaos removes Tansley's (1935) theoretical objection to the concept of an ecosystem displaying complex emergent behavior which is unpredictable from its components. It is possible to know exactly how some extremely simple systems work, and still not be able to predict their trajectories.

But complex adaptive systems do not necessarily display chaotic behavior; they may be characterized by unexpectedly simple behaviors, emergent properties unpredictable from the characteristics of the components alone. Chaos and complexity are conceptually linked: "whereas chaos is the science of how simple things produce complex behavior, complexity is the study of how complex collections of simple units produce a wide variety of behavior (Flake 1998)." Complex adaptive systems are characterized by complexity and adaptation (obviously), but more importantly by the emergent global patterns arising from the localized interaction and adaptation of multiple independent components (Levin 1998). These emergent global patterns are termed self-organization ("order for free," Kauffman 1995), because in complex adaptive systems they arise despite a lack of global control. Kauffman (1995) argues that self organization is a result of complexity itself in his quest for laws of universal organization, but in resource management, we only need to understand that these systems are complex and self organized, and that certain behavior might therefore be expected. One characteristic of complex adaptive systems is path dependence, "a consequence of nonlinearity, which refers simply to the fact that the local rules of interaction change as the system evolves and develops. (Levin 1998)" Another behavior most pertinent to ecosystem based management also resulting from nonlinearity is that complex adaptive systems experience rapid phase transitions between multiple states (Flake 1998, Levin 1998). A special case of the phase transition is termed "self organized criticality," where a system maintaining itself near a threshold may cross a critical boundary with a small alteration that creates a large disruption, but the disruption itself then restores the system to its original position. A sand pile is a simple example of self organized criticality, where the addition of a grain to the top may change nothing or may cause an avalanche, which in turn reinstates the stability of the pile when it comes to rest (Flake 1998). This appears to be analogous to the homeostasis in Odum's ecosystem concept, but one requiring a bit of self imposed destruction to restore the previous state. The main difference between the complex adaptive ecosystem concept and that prevailing from Tansley through Odum (and beyond) is that complex systems are by definition non-equilibrium systems (Levin 1998).

Seeing an ecosystem as tending towards an equilibrium state allows us to optimize simple models and to believe in the predictability (and reversibility) of the outcomes of our manipulations, but what does seeing the ecosystem as a complex adaptive system do for us? Our former deterministic confidence in exact outcomes cannot be maintained. The good news is that we can see general patterns of behavior in these systems ("attractors" which occupy finite spaces, see Gleick 1987), even though exact trajectories within attractors are unpredictable. The adjustment we need to make is in how we use our knowledge of limited predictive capability effectively in management and recognize patterns that are predictable, rather than putting ever more resources into pursuing the unattainable goal of getting enough knowledge to predict precise outcomes of specific manipulations within complex systems. We can understand some system characteristics that will be helpful in managing our actions and improving our future prospects, but we can only do this if we let go of the idea of ecosystems as engineered controllable machines. Seeing the ecosystem as a complex adaptive system provides necessary balance—neither extreme concept of nature as pure chaos or as controllable machine is useful or realistic for ecosystem-based management. I will give examples of complex adaptive behavior in coastal marine ecological/economic systems in this dissertation, first in historical terms in the remainder of chapter 1, then in analytical terms in chapters 2 and 3. Based on this concept of the Gulf of Alaska ecosystem as a complex adaptive system, as well as the concept of ecosystem sustainability developed below, I will suggest methods for implementing ecosystem-based fishery management in chapter 4.

Towards a concept of ecological sustainability

Viewing ecosystems as complex adaptive systems may assist in defining sustainability at the ecosystem level, a necessary prerequisite to ecosystem based management. Sustainability itself is a slippery, context dependent concept. There are several possible definitions and uses for the word "sustainable":

> (From the OED) Sustainable (adj): 1. Capable of being borne or endured; supportable, bearable. 2. Capable of being upheld or defended; maintainable. 3. Capable of being maintained at a certain rate or level.

At present, the concept of fisheries sustainability is encoded within our models and policy in the form of Maximum Sustainable Yield (MSY). It is fairly easy to understand "sustainable yield" given these definitions. It is a yield or catch that can be endured (by a resource), that can be maintained (over time), and maintained at a certain level (over time). Maximum sustainable yield, then, is obviously maintained at the maximal level that is bearable over time by the resource. But is it really so simple? The references to time the sentence above in are not in the dictionary definition, but arise from mathematical formulations and assumptions about equilibrium behavior in population models. They were then written into the law of the land, which was viewed as a positive step towards conservation (the "Fisheries Conservation and Management Act"). Therefore, the concept of sustainable yield in fisheries can be seen as a product of both forms of human language—verbal and mathematical—which is itself sustained by social institutions. From a human point of view, maintaining yield at a certain (maximal) rate or level over time implies that we are getting everything we can, which we think is best for us. From the resource viewpoint, however, this is something that the resource has to "endure," which implies stress, and constant maximal stress at that. Our language, math, and laws say we should subject the resource to the most stress it can bear over time, because we want the most we can get. Is this the type of sustainability we want to apply at the ecosystem level?

Recently, the concept of ecological sustainability has been approached by several authors. Here, I briefly outline the ideas of Solow (1998), Francis (2001), McEvoy (1986, 1996), Holling (1995, 2001), and Worster (1993). In general, each author emphasizes the need to go beyond reductionist scientific study of system components, to emphasize relationships between components across multiple scales, and also to include historical, economic, and cultural relationships within a system. These ideas are more easily associated with the concept of the ecosystem as a complex adaptive system (Levin 1998), rather than as an engineered equilibrium system (Tansley 1935).

Solow (1998) gives an economist's perspective on the general concept of sustainability, which provides a foundation within the social sphere for the discussion of ecosystem sustainability. He has four main points. First, he describes sustainability as a general moral obligation to future generations to preserve their ability to prosper at least as much as the current generation. Solow states that this does not imply future generations must have access to exactly the same resources we do, but to equivalent resources, and that this access to the resources ensuring prosperity should be achieved via the application of policy that is robust over a wide range of future situations, as many as we can envision in the present. Solow's second point is that the policy applied to promote sustainability must consider saving and investment for the future as well as consumption in the present. He mentions that simple reliance on supply and demand or other economic market forces is not likely to ensure sustainability because market forces are based in the present or at best in the very short-term future (this is illustrated nicely by the historical exploitation patterns in the Gulf of Alaska in the next section), so policy should include measures extending beyond simple free market economics. These first two points imply that environmental protection measures contribute to sustainability if they curtail current consumption and therefore promote investment in the future, but do not if they prevent investment in future prosperity (eg, full closure of all fisheries forever may preserve biomass, but will not feed the future). Third, Solow points to the fundamental conflict inherent in the concept of sustainability between the moral obligation of investment for future generations and the moral obligation to improve the standard of living for people who are poor in the present, thus increasing present consumption. Solow does not suggest a solution, but rather suggests that simply facing this conflict is an important part of policy making for sustainability. The fourth and perhaps the most useful point raised in Solow's perspective is "that sustainability is an essentially vague concept, and it would be wrong to think of it as being precise, or even capable of being made precise. It is therefore probably not in any clear way an exact guide to policy (Solow 1998)." This seems to suggest that the idea of Maximum Sustainable Yield, a mathematically precise concept for fished populations which underlies the fisheries policy in the Magnuson Act, represents at best incomplete policy guidance for a broader goal of ecosystem sustainability in a socio-economic context. This idea is also reflected within the more fishery specific context of Francis (2001) and McEvoy (1986, 1996)

Francis (2001) frames the discussion of sustainability and marine conservation by identifying two conceptual tools important to understanding: mathematics and history. Mathematics allows us to connect system processes conceptually, but history is also crucial because current conditions in a complex system are dependent on the previous sequence of events in the system. Francis suggests that our policy for sustainability must be defined across multiple timescales including those that exceed human generation time. Further, as McEvoy (1986, 1996) also argues, we should focus not on sustaining biomass of one stock or favorable economics (yield) for one user group—we should be sustaining the relationships between components of the linked systems. It is the "long term health of the interaction between nature, the economy, and the legal system" which must be maintained over time (McEvoy 1996). The concept of sustainability must address connectedness of the ecological, economic, and social systems because interactions between systems may cause sudden change in one or all of them. The sudden change comes about under conditions where slow, continuous change in any one system may have no observable effect, but then one apparently small additional change flips the system, or a connected system, or all of the systems into crisis mode (an observation directly related to the concept of phase transitions and "self organized criticality" in complex adaptive systems (Flake 1998)). However, "crisis" may be less painful if change is understood as inherent in complex system structure, and is incorporated within the concept of ecosystem stability as Holling (1995, 2001) suggests.

Holling's (2001) "panarchy" combines and coordinates the previously existing complex adaptive systems concepts of hierarchy and adaptive cycles across scales to help conceptualize ecosystem sustainabilty. For Holling, the key characteristic of a hierarchy is information flow between levels—not all of it gets through. Therefore, we can separate within-level processes from between-level processes in the hierarchy. Holling defines the within-level processes as adaptive cycles (with dynamics described by an "infinity" loop incorporating system growth, accumulation, restructuring, and renewal (Holling 1995)) and emphasizes that these levels are nested rather than aligned vertically. Between-level relationships have two forms: a lower level collapse which precipitates collapse at a larger scale, and the stabilizing restorative force of a larger level process damping out smaller scale shocks—reorganizing or maintaining organization. The panarchy as a whole, similarly to a complex adaptive system, is therefore described as "both creative and conserving." Events at different scales cause different disturbances—small scale within-level events have no impacts on the panarchy as a whole, while large scale but rare events can upend an entire set of levels in the panarchy. The renewal process must then take place across multiple scales. Renewal, however, is not reversal or the return to the original (only) equilibrium as expected in simple population dynamics models. As Holling points out, a large scale crisis "clears the decks" for new opportunities; the system can explore whole new spaces (e.g., ecological niche spaces, economic markets). So while success carries the seeds of its own downfall, destruction creates potential for new and different kinds of success—and multiple, short-lived "steady states." As also identified in Francis (2001) and McEvoy (1986), time sequences of long periods of stability followed by rapid shifts and reorganization have been observed in many systems at many scales—ecosystem regime shifts (see below) social dynamics, etc. "Periods of success carry the seeds of subsequent downfall" because the system becomes rigid. Holling's panarchy concept precludes the simple tendency towards equilibrium or homeostasis as the characteristic behavior of ecosystems. Therefore, ecosystem sustainability must be redefined as well. Within the panarchy framework, Holling defines sustainability as "the capacity to create, test, and maintain adaptive capability." This sounds quite similar to the economist's perspective on sustainability, which is "to leave the future the option or the capacity to be as well off as we are (Solow 1998)." Health in a system is then defined by Holling as the ability to benefit from inventions that create opportunity while being kept safe from destabilizing forces. Processes at a given level of organization are "invigorated" from below (by smaller scale fast processes), and "protected" from above (by larger scale slow process). Holling agrees that history is important within the panarchy framework. Reflecting the conclusions of Francis and McEvoy, Holling agrees that "knowing where you are helps you define what action needs to be taken."

Like Holling, Worster (1993) seeks a definition of sustainability, but one defined in a social context, similar to the economic perspective of Solow (1998). Sustainability first appeared in cultural consciousness in the sense of sustained yield—MSY described above. Worster traces the historical development of sustained yield as an idea arising from the view of nature as machine (which we observed in the development of the ecosystem concept), where human science figures out the controls of the machine and then dutifully manipulates those controls to produce stability and prosperity from the otherwise untamed and inefficient system. From the social standpoint, sustained yield was a tool for economic growth, providing the foundation of social order (in part due to its perceived predictability). Control by the state was necessary to provide sustained yield and its associated social order, because self interested entities harvesting natural resources would overexploit them due to short term incentives. According to Worster, society therefore needs government bureaucracies and technically trained individuals to provide sustainability of natural resources. It should be no surprise then, he argues, that agencies established for such a purpose view nature as a commodity to be managed in a social context for societal good. For example, the Magnuson Stevens Fishery Conservation and Management Act prioritizes management that "will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunites, *and taking into account the protection of marine ecosystems*." The italicized portion was added recently, underlining the need to connect the ecological sphere with the social and economic. Society is beginning to see the connections between spheres, and to realize that costs to sustain ecosystems are worth paying. Lessons of history indicate that global human impacts are real, and surprises (unpleasant ones like the ozone hole) are likely as we extend our impacts via technology. Worster argues that the recent cultural worldview which results in these self destructive global impacts is materialistic and distinctly modern. The characteristics of modern materialism are that it is secular (here and now valued over spiritual, afterlife), progressive (cycles not valued, processes should always increase, improve in linear fashion, old is bad), and rational (over-confidence that humans can discover laws of nature and use them to advantage). Both economics and science currently share this worldview, as they are connected by a common culture. Adam Smith is characterized as the harbinger of modern attitude (that has to change): his ideas defined it to be "natural" for humans to want to increase material comforts, to "Possess in abundance." In this framework, nature is only valuable if it increases human material comfort. Worster concludes that the environmental crisis brought on by modernity and materialism can only be reversed by a shift in worldview to one that values nature intrinsically, that doesn't go back to some previous time of superstition but acknowledges the limitations of our science and technology. Understanding and accepting that you cant know everything implies respect for the system, the basis of new worldview. Worster, Francis, and McEvoy echo each other's recommendations to respect nature as much as human culture, and to bring the social, economic and ecological spheres onto equal footing in order to achieve ecological sustainability.

In defining ecosystem sustainability, I suggest a combination of concepts from Holling, Francis, McEvoy, Solow, and Worster. Holling provides a framework for thinking about management and sustainability in a complex adaptive systems context. The framework identifies where systems are predictable and where they are not—growth is predictable, so is collapse (that it will happen, not necessarily when or how)—the new shape of the system is not predictable at reorganization phase, but the process of renewal and growth is predictable. Predictable system trajectories may be important to management, at least as we view fisheries management now, but is it realistic to expect this from complex adaptive systems? Ecosystem based management could focus on predicting patterns and processes, rather than time-specific events (e.g., we know the earthquake will hit on the Cascadia fault, but we don't know exactly when) to foster sustainability in between social, economic, and ecological spheres. The management policy would have to be robust to the recognized uncertainty, as suggested by Solow, to allow the future capacity to adapt and prosper under the conditions determined both by our present actions and by forces beyond our control. In the earthquake example, retrofitting structures is a policy representing investment in the future, which may reduce consumption in the present by redirecting disposable income. Ecosystem based fishery management would promote sustainability via similar policy to protect vulnerable infrastructure within ecosystems.

Francis, McEvoy, and Worster all emphasize the importance of learning from history and understanding the relationships between culture, science, economics, and management. Understanding science as just one component of a worldview inclusive of culture and history creates a broader perspective on sustainability, and allows us to visualize the future with more possibilities, perhaps less hampered by unexamined discipline-specific assumptions. Rewriting MSY in terms of the broader definitions of sustainablility and then viewing the result in terms of Worster's discussion of modern materialism is a useful exercise: "Our language, math, and laws say we should subject the resource to the most stress it can bear over time, because we want the most we can get." The policy of MSY does not allow us to broaden the perspective to social, economic, or even ecological viewpoints. Within the single species MSY context, we don't currently ask whether we need the most we can get. Or whether the most we can get allows future generations to prosper in the manner that we do, or at least allows all of us here in the present to prosper equally. Or whether, as members of the ecosystem, we have the right to subject other living things to the most stress they can bear. Addressing these specific cultural questions would be a step toward ecological sustainability.

The message of complex adaptive systems is that at the system level there are limits to what science knows and can know (Francis 2001, Levin 2002). Francis/McEvoy and Worster emphasize emotional and spiritual aspects of understanding complex systems and promoting their sustainability. Holling doesn't address emotion or spirit, but does argue for encouraging people to accept change. Consensus as a key factor in defining sustainability in large systems and on a global scale is only mentioned explicitly by Worster, and tangentially by Solow. We must go beyond science to understand emotionally that relationships between things are as important as the things themselves, even if we cannot identify all of the relationships. We must also go beyond science to recognize sustainability as a moral obligation to the future. Going beyond science requires faith, a concept often divorced from science, but it is necessary to reunite the two in a healthy relationship if we are to develop ecological sustainability. Kauffman (1995) suggests that a "spiritual hunger remains" after digesting the modern materialistic worldview; one which might be fed by "reinventing the sacred." His vision makes space for the sacred concept of order in the universe by combining Darwinian selection with complex adaptive systems' self organizing properties, thus bringing a comforting structure—laws of life—back to the science of evolutionary biology, formerly ruled only by chance. In ecosystems science, the leap of faith is similar. The scientifically difficult concept of ecosystem "health" may be more obvious in an emotional context when we can be aware of all the parts functioning by themselves and their relationships' emergent properties, *without necessarily understanding them all*, instead of concentrating on the disaggregated roles of individual parts, or single indicators. "Focusing on one point is concentration. Focusing on all points at the same time is meditation. Meditation is centrifugal as well as centripetal." (Iyengar 1988) Reductive science is concentration, but to comprehend ideas like ecosystem health, "to create a culture of sustainability," we need something more like meditation.

Conclusion, and Introduction to Chapter 1 Part 2

The complex adaptive ecosystem may be best described as a series of interwoven life histories, adapted to local conditions, physical and biological, evolving together with emergent properties based on the relationships between and characteristics of the individual occupants. These relationships include not just the life histories of marine organisms, but also of humans, with our interwoven economic interests and agencies, which have shifted over time in response to evolving ecology, markets, and politics. A focus on all of these points at the same time, a system meditation, is what we need as context for ecosystem sustainability, but in the marine environment we have a significant handicap; this is not an ecosystem we can inhabit or even walk through briefly and experience. We sense it by the remotest of means. The distance allows us to build management myths rooted primarily in the human life history, like stock specific MSY, which exist outside the context of the ecosystem, firmly in the social and economic sphere, and even there too narrowly defined. Walking through an old growth forest in the Pacific Northwest, or a desert, or a marsh, we develop a visceral understanding of the ecosystem, even if we miss most of its parts or don't understand their relationships. While we may exploit it, we can still experience the terrestrial ecosystem, if even for a moment, by occupying it with attention, and meditation. We understand the physical structure and the space, the temperature, the scents, the tastes, textures, and colors, the level of shelter and complexity, things we can relate to on a personal basis. We can experience the relationships established and altered by our exploitation. Developing the same feel for a marine ecosystem presents a difficult meditation, but one which is crucial to attempt.

To promote sustainability via ecosystem based management, we need to identify vital relationships in a marine ecosystem, and then determine a range of policy options that protect the infrastructure of relationships so that adaptive capacity is maintained for the future—both of the ecosystem and the economy dependent on it. The first step is to understand that the history of the system and the relationships within it today are inextricable; in fact, sometimes all we know about system history may be the relationships we observe today. With information gleaned from historical reconstruction, we must then employ our best remote sensing tools, ensembles of mathematical models that integrate the information arriving from diverse sources. Modeling used to its full potential is one of our best methods for testing a range of policy options against the known patterns and processes, the unknown relationships, and the unknowable future, in a marine ecosystem management context where decision making must be transparent to a diversity of stakeholders, and must happen on an annual, if not daily, basis.

References for Chapter 1 Part 1

Beverton, R.H., and S.J. Holt 1957. On the dynamics of exploited fish populations. Chapman & Hall, London, 538 pp.

Bocking, S. 1994. Visions of nature and society: a history of the ecosystem concept. Alternatives 20(3): 12-17.

Carson, R. 1962. Silent Spring. Houghton Mifflin Company, New York. 378 pp.

Flake, G.W. 1998. The computational beauty of nature. Computer explorations of fractals, chaos, complex systems, and adaptation. The MIT Press: Cambidge MA, 495 pp.

Francis, R.C. 2001. Some thoughts on sustainability and marine conservation. Fisheries27(1):18-22.

Gleick, J. 1987. Chaos: making a new science. Penguin Books, New York, 352 pp.

Hilborn, R., and C.J. Walters, 1992. Quantitative fisheries stock assessment: choice, dynamics, and uncertainty. Chapman & Hall, New York, 570 pp.

Holling, C.S. 1995. What barriers? What bridges? Chapter 1 in Gunderson, Holling, and Light (eds.). Barriers and Bridges to the renewal of ecosystems and institutions. New York: Columbia University Press, 593 pp.

Holling, C.S. 2001. Understanding the complexity of economic, ecological and social systems. Ecosystems 4:390-405.

Hutchinson, G.E. 1942. Addendum. Ecology 23(4): 417-418.

Iyengar, B.K.S. 1988. The tree of yoga. Shambhala Publications, Inc.: Boston. 194 pp.

Kauffman, S.A. 1995. At home in the universe: the search for laws of self organization and complexity. Oxford University Press: Oxford. 321 pp.

Levin, S.A. 1998. Ecosystems and the biosphere as complex adaptive systems. Ecosystems 1: 431-496.

Lindeman, R.L. 1942. The trophic-dynamic aspect of ecology. Ecology 23(4): 399-417.

May, R.M. 1987. Chaos and the dynamics of biological populations. Pp 27-44 in Dynamical Chaos: Proceedings of the Royal Society of London. Princeton University Press: Princeton NJ, 199 pp.

McEvoy, A.F. 1986. The Fisherman's Problem: Ecology and Law in California Fisheries, 1850-1980. Cambridge U. Press, New York.

McEvoy, A.F. 1996. Historical interdependence between ecology, production, and management in California fisheries. pp 45-53 in D. Bottom, G. Reeves and M. Brookes (eds.) Sustainability Issues for Resource Managers. USDA Forest Service Tech Rep. PNW-GTR-370.

Odum, E.P. 1969. The strategy of ecosystem development. Science 164: 262-270.

Odum, E.P. 1977. The emergence of ecology as a new integrative discipline. Science 195: 1289-1293.

Odum, H.T. 1994. Ecological and General Systems: An Introduction to Systems Ecology. University Press of Colorado.

Solow, R.M. 1998. Sustainability: An Economist's Perspective. pp 450-455 In Vandeveer and Pierce (eds), The Environmental Ethics And Policy Book, 2nd Edition. Wadsworth.

System of a Down. 2001. Science. Track 10 on Toxicity. Sony Music Entertainment Inc.

Tansley, A.G. 1935. The use and abuse of vegetational concepts and terms. Ecology 16(3): 284-307.

Worster, D. 1993. The Wealth of Nature: Environmental History and the Ecological Imagination. Oxford Univ. Press.