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Thinking of Environmental Law as a Complex Adaptive System: How to Clean Up the Environment by Making a Mess of Environmental Law

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THINKING OF ENVIRONMENTAL LAW AS A COMPLEX ADAPTIVE SYSTEM: HOW TO CLEAN UP THE ENVIRONMENT BY MAKING A MESS OF ENVIRONMENTAL LAW

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I prepared this Article in anticipation of delivering the A.L. O'Quinn Lectures in Environmental Law at the University of Houston Law Center, and I am indebted to that institution for bestowing that honor upon me and inspiring me to consider the full implications of complex adaptive systems theory on environmental law. I also owe special thanks to John Mixon of the University of Houston Law Center, the Gruter Institute for Law and Behavioral Research, and the Southern Illinois University Geography Department, each of which allowed me to present lectures based on earlier versions of this Article and thus both contributed to and endured the work in progress, and to Jim Salzman, John Nagle, and Thomas Geu for their useful comments on earlier drafts of this Article. Please address comments and questions to jbruhl@siu.edu.

I. INTRODUCTION

The environment is a mess. I do not mean that the environment is polluted, or unsightly, or ravaged by what humans have done to it. To be sure, the environment is a mess in that sense in many places, and that type of messiness is not outside the scope of what follows in this Article. For the moment, however, the mess to which I refer is the inherently chaotic and dynamical state in which the environment exists. The environment in that sense has been compared in its complexity to the human brain and the global economy.[1] The richness and diversity of ecological systems in the environment defy our full grasp, as they are "continually in flux and exhibit a wondrous panoply of interactions such as mutualism, parasitism, biological arms races, and mimicry .... Matter, energy, and information are shunted around in complex cycles."[2] In other words, the environment operates in a state of highly complicated, organized disorder. Indeed, scientists are beginning to understand that the disorder—the chaos that is inherent in the environment—is its means of sustainability.[3]

As for the other kind of mess—the one humans have made of the environment—what seems most pernicious and insidious about it is its capacity to cut through the dynamical qualities of the environment. In other words, many of the consequences of land use, resource development, and pollution undermine the diversity, chaos, and other adaptive qualities of the environment that are essential to its long-term survival.[4] Our use and degradation of the environment through actions such as conversion of wetlands to agriculture, logging in old growth forests, stream channelization, dams on rivers, oil spills, and acid rain cannot avoid undermining the dynamical messiness of the environment

1. *See* James H. Brown, *Complex Ecological Systems*, *in* COMPLEXITY: METAPHORS, MODELS, AND REALITY 419, 421 (George A. Cowan et al. eds., 1994).

2. JOHN H. HOLLAND, HIDDEN ORDER 3 (1995).

3. *See id.* at 4 (stating that "the question of coherence under change is the central enigma for each [complex system]").

4. *See id.* (relating that our survival depends on our ability to use ecosystems without destroying them).

even when carried out using the best available means of environmental protection.[5]

Neither of these themes is particularly new. Darwin heralded the flux of ecosystems as an agent of biological evolution.[6] Rachel Carson awakened a generation of Americans to the ways in which human actions interfere with environmental dynamics.[7] What is new, however, is the method we can use to understand the forces at play in the complex interaction of the environment and human society. That method is complexity theory—the study of complex adaptive systems.[8]

Complexity theory and the science of complex adaptive systems have radically altered the way in which scientists study natural systems as mundane as a dripping faucet and as grand as the weather.[9] In fairness, the underlying subject matter of complexity theory—nonlinear, irreversible behavior in complex adaptive systems—has been a matter of scientific inquiry since before Newton. For centuries, however, the classical scientific method has approached such behavior in a reductionist manner intent on studying components of whole systems at their most

5. This effect is often referred to as "environmental simplification." *See* Janet N. Abramovitz, *Valuing Nature's Services*, *in* STATE OF THE WORLD 1997, 95, 108 (Linda Starke ed., 1997); *see also* HOLLAND, *supra* note 2, at 4 (stating that attempts to "efficiently" turn tropical forest into farmland, or to fish the Grand Banks "efficiently" are symptoms of a flawed approach that become more serious year by year).

6. Many modern biologists credit Darwin as helping to establish the science of ecology through his recognition that a "'web of complex relations' binds all of the living things in any region." JONATHAN WEINER, THE BEAK OF THE FINCH 225 (1994) (quoting Charles Darwin's *Origin of Species*). *See also* Peter Taylor, *Community*, *in* KEYWORDS IN EVOLUTIONARY BIOLOGY 52 (Evelyn Fox Keller & Elisabeth A. Lloyd eds., 1992) (describing Darwin's acknowledgment of the importance of ecological contexts).

7. *See* RACHEL CARSON, SILENT SPRING 5 (1962) (stating that man is the first species to actually mold its surroundings, rather than being molded by its surroundings).

8. Complexity theory refers to the body of literature and research devoted to "the study of the behavior of macroscopic collections of [interacting] units that are endowed with the potential to evolve in time." PETER COVENEY & ROGER HIGHFIELD, FRONTIERS OF COMPLEXITY 7 (1995). Although the study of such systems can be quite technical in substance, many of the recent and most influential works in the field focus on applications of the technical theory to real world phenomena, such as biological evolution. *See, e.g.*, JOHN L. CASTI, COMPLEXIFICATION: EXPLAINING THE PARADOXICAL WORLD 166-70 (1994) [hereinafter CASTI, COMPLEXIFICATION]; JACK COHEN & IAN STEWART, THE COLLAPSE OF CHAOS 371-73 (1994); MURRAY GELL-MANN, THE QUARK AND THE JAGUAR 235-60 (1994); BRIAN GOODWIN, HOW THE LEOPARD CHANGED ITS SPOTS: THE EVOLUTION OF COMPLEXITY at x (1996). *See generally* STUART KAUFFMAN, AT HOME IN THE UNIVERSE (1995) [hereinafter KAUFFMAN, AT HOME IN THE UNIVERSE]; STUART KAUFFMAN, THE ORIGINS OF ORDER (1993) [hereinafter KAUFFMAN, ORIGINS OF ORDER].

9. *See* HOLLAND, *supra* note 2, at 1-4 (illustrating how complexity theory guides understanding and study of how life continues in large cities and of microscopic systems such as the human immune system).

irreducible levels, based on the premise that by understanding how each part works, we can understand the whole system.[10] With the advent of high-speed computers that allow system modeling at levels of detail never before imagined, complexity theory has shattered the classical reductionist methodology in virtually every field of physical science and has emerged as an important force in social sciences as well.[11] As powerful as reductionism can be as a means of approximating system results—Isaac Newton, after all, was a reductionist, and he explained much about the physical world[12]—complexity theory shows that the reductionist methodology will never lead to a fully predictive theory of any complex system.[13]

I believe that complexity theory has much to offer in our understanding of environmental law.[14] Certainly anything that im-

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10. By reductionism, I mean the "doctrine according to which complex phenomena can be explained in terms of something simpler." COVENEY & HIGHFIELD, *supra* note 8, at 432. Reductionism leads to the belief that an observable, complex phenomenon can be studied and fully understood by first reducing it to the simplest, indivisible subcomponents in operation during the phenomenon, then studying each of those subcomponents, and then reassembling them to gain a full understanding of the rules of operation of the whole phenomenon. That form of reductionism has long predominated as an organizing principle for classical scientific inquiry. *See* CASTI, COMPLEXIFICATION, *supra* note 8, at 12-14 (providing a checklist of the characteristics of scientific rules); COHEN & STEWART, *supra* note 8, at 33-34 (discussing the reductionist approach and characterizing it as "the forefront of scientific methodology").

11. For a discussion of the importance of computers to systems modeling and the emergence of complexity theory, see JOHN L. CASTI, WOULD-BE WORLDS 35 (1997). For histories of the development of complexity theory, which has been brought about largely through the efforts of the Santa Fe Institute, see JAMES GLEICK, CHAOS: MAKING A NEW SCIENCE 3-8 (1987); ROGER LEWIN, COMPLEXITY: LIFE AT THE EDGE OF CHAOS 8-22 (1992). *See generally* M. MITCHELL WALDROP, COMPLEXITY (1992). Current information about the field is best obtained from the journal *Complexity*.

12. *See* MICHAEL H. HART, THE 100: A RANKING OF THE MOST INFLUENTIAL PERSONS IN HISTORY 41-46 (Citadel Press 1987) (1978) (stating that Newton was the most influential scientist in the development of scientific theory); JOHN SIMMONS, THE SCIENTIFIC 100: A RANKING OF THE MOST INFLUENTIAL SCIENTISTS, PAST AND PRESENT 3-4 (1996) (characterizing Newton as the most influential figure in the history of Western science and crediting him with much of our knowledge of the physical world).

13. *See* HOLLAND, *supra* note 2, at 15-16 (stating that using linear functions to study complex adaptive systems is "like trying to play chess by collecting statistics on the way pieces move in the game"); GLEICK, *supra* note 11, at 3 (explaining that "[w]here chaos begins, classical science stops"); GOODWIN, *supra* note 8, at vii-xiii (explaining the limits in Darwin's approach to evolution).

14. Although the commentary on this subject is still quite nascent, I am glad to be joined by at least a few other commentators in advocating a complex adaptive systems approach for environmental law and policy. In an essay that provides an excellent overview of the difficulties of the emerging environmental law issues and politics and the "fit" between them and complex adaptive system qualities, Professor Gerald Emison concludes that the use of complex adaptive systems theory "expands the means for environmental protection so that innovation and improvement, rather

proves our understanding of how the environment works, as many scientists believe complexity theory has done, should also improve our ability in the long run to manage the environmental consequences of social activity. But my focus is not exclusively on nature's dynamical environmental system; rather, we must also consider the dynamical forces within the legal system we devise to manage our impacts on the environment. Law, in other words, has the capacity to operate as a complex adaptive system.[15]

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than control and protection, become the major functions of environmental quality management." Gerald Andrews Emison, *The Potential for Unconventional Progress: Complex Adaptive Systems and Environmental Quality Policy*, 7 DUKE ENVTL. L. & POL'Y F. 167, 192 (1996). Emphasizing more the implementation of that model and less the complex adaptive systems theory, Professor Alistair Iles outlines an excellent approach to the adaptive management policy theme that I contend is most compatible with what the complex adaptive systems theory suggests must be the future of environmental law. *See* Alastair Iles, *Adaptive Management: Making Environmental Law and Policy More Dynamic, Experimentalist and Learning*, 10 ENVTL. & PLAN. L.J. 288 (1996). For a similar argument linking complexity theory and sustainable development, the policy principle which I contend is the most compatible with the view of environmental law as a complex adaptive system, see generally ANTHONY M. H. CLAYTON & NICHOLAS J. RADCLIFFE, SUSTAINABILITY: A SYSTEMS APPROACH (1996). What I hope to offer in this Article, in addition to these highly recommended readings, is a deeper examination of the case for using complex adaptive systems theory as a broad foundation for environmental law and policy and a more explicit connection between that theoretical foundation and the practical organizing principles for implementation.

15. Elsewhere, I have laid out the basic model of how the sociolegal system can be portrayed as a complex adaptive system and how the findings of complexity theory can contribute to an understanding of the mechanics of how that system behaves and evolves. *See* J.B. Ruhl & Harold J. Ruhl, Jr., *The Arrow of the Law in Modern Administrative States: Using Complexity Theory to Reveal the Diminishing Returns and Increasing Risks the Burgeoning of Law Poses to Society*, 30 U.C. DAVIS L. REV. 405, 407 (1997) [hereinafter Ruhl & Ruhl, *Arrow of Law*] (discussing the direction in which the behavioral and evolutionary mechanics are leading the sociolegal system given its current transient state); *see also* J.B. Ruhl, *Complexity Theory as a Paradigm for the Dynamical Law-and-Society System: A Wake-Up Call for Legal Reductionism and the Modern Administrative State*, 45 DUKE L. J. 849, 927 (1996) [hereinafter Ruhl, *Complexity Theory as a Paradigm*] (arguing that law and society coexist interdependently and dynamically similar to the behavior of nonlinear systems in the physical world); J.B. Ruhl, *The Fitness of Law: Using Complexity Theory to Describe the Evolution of Law and Society and Its Practical Meaning for Democracy*, 49 VAND. L. REV. 1407, 1419-37 (1996) [hereinafter Ruhl, *Fitness of Law*] (discussing the general evolutionary model). For additional descriptions of how complexity theory or branches of it help explain how law behaves and evolves generally, see Vincent Di Lorenzo, *Legislative Chaos: An Exploratory Study*, 12 YALE L. & POL'Y REV. 425, 432-35 (1994) (developing a model for legislative decisionmaking based on chaos theory); Thomas Earl Geu, *The Tao of Jurisprudence: Chaos, Brain Science, Synchronicity, and the Law*, 61 TENN. L. REV. 933, 934-35 (1994) (discussing the potential significance of chaos and emergence to legal theory); Andrew W. Hayes, *An Introduction to Chaos and Law*, 60 UMKC L. REV. 751, 764-73 (1992) (containing a general discussion of chaos theory and its application to judicial decision making); Mark J. Roe, *Chaos and Evolution in Law and Economics*, 109 HARV. L. REV. 641, 643-65 (1996) (describing legal evolution according to path dependence theory and chaotic systems theory); Robert E. Scott, *Chaos Theory and the*

In this Article, I explore the significance of that proposition for environmental law. Understanding law as a complex adaptive system brings into focus three major themes for environmental law. The first theme, explored in Part I of this Article, is that the subject matter of environmental law consists of interlinked complex adaptive systems. The foundation of complexity theory is the study of five behavioral properties of complex adaptive systems that lead to their sustainability: (1) the aggregation of a system's many component parts;[16] (2) the dissipative flow of energy, information, or other mediums through the system;[17] (3) the nonlinear path of system evolution;[18] (4) the diversity of system components and behavior;[19] and (5) the drive toward self-critical behavior as the stable nonequilibrium system state.[20] Complexity theory demonstrates that these behaviors must exist for the system

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Justice Paradox, 35 WM. & MARY L. REV. 329, 329-31 (1993) (applying chaos theory to the legal dilemma between "present justice" and "future justice"); and Kenton K. Yee, *Coevolution of Law and Culture: A Coevolutionary Games Approach*, COMPLEXITY, Jan.-Feb. 1997, at 4 (describing attempts to mathematically model evolution of common law according to complex adaptive systems dynamics). Several other works discuss complexity theory or its branches, sometimes very briefly, in specific legal settings. *See* Lawrence A. Cunningham, *Capital Market Theory, Mandatory Disclosure, and Price Discovery*, 51 WASH. & LEE L. REV. 843, 854-59 (1994) (applying chaos theory to capital market regulation); Lawrence A. Cunningham, *From Random Walks to Chaotic Crashes: The Linear Genealogy of the Efficient Capital Market Hypothesis*, 62 GEO. WASH. L. REV. 546, 581-92 (1994) (discussing the application of chaos theory to capital market regulation); Michael J. Gerhardt, *The Role of Precedent in Constitutional Decisionmaking and Theory*, 60 GEO. WASH. L. REV. 68, 114-15 (1991) (explaining Supreme Court constitutional jurisprudence using, among other mediums, a discussion of chaos theory); Alistair M. Hanna, *The Land Use System*, 13 PACE ENVTL. L. REV. 531, 538 (1996) (discussing application of chaos theory and self-organization theory to land use regulation system); Glenn Harlan Reynolds, *Chaos and the Court*, 91 COLUM. L. REV. 110, 112-15 (1991) (explaining Supreme Court constitutional jurisprudence using chaos theory); William H. Rodgers, Jr., *Where Environmental Law and Biology Meet: Of Pandas' Thumbs, Statutory Sleepers, and Effective Law*, 65 U. COLO. L. REV. 25, 46-48 (1993) (discussing chaos theory surfacing in evolutionary biology commentary as a metaphor for evolution of environmental law); *see also* MICHEL VAN DE KERCHOVE & FRANCOIS OST, LEGAL SYSTEM BETWEEN ORDER AND DISORDER 102-77 (Iain Stewart trans., 1994) (discussing order-disorder tensions in legal systems); Eric Kades, *The Laws of Complexity and the Complexity of Laws: The Implications of Computational Complexity Theory for the Law*, 49 RUTGERS L. REV. 403, 452-54, 476 (1997) (focusing on mathematically complex issues as they arise in law, such as cyclical priority issues in liens and property titles); Lynn M. LoPucki, *The Systems Approach to Law*, 82 CORNELL L. REV. 479, 480-82 (1997) (advocating an empiricist "systems approach" to legal analysis).

16. *See* HOLLAND, *supra* note 2, at 10-12.

17. *See id.* at 23-27.

18. *See id.* at 15-23.

19. *See id.* at 27-31.

20. Refer to part II.A.5 *infra* (discussing the self critical behavior of complex adaptive systems).

to adapt successfully over the long run in the face of external disturbances. Based on a burgeoning wealth of unfolding research in complexity theory being undertaken in a variety of fields, I demonstrate that these properties are found in many of the systems that are the subject matter of environmental law, such as ecosystems, technology, economies, and land use.

The realization that environmental law is fundamentally an endeavor to regulate many complex adaptive systems leads to the second theme, examined in Part II of this Article, which is that our present framework of environmental law is designed as if its subject matter is dictated by uniformitarianism[21] rather than a set of dynamic, adaptive systems. Complex adaptive systems, because of their highly collectivized, nonlinear, dynamic behavior, defy prediction through classical reductionist method, or any other known method for that matter. Yet we have not designed our environmental law system with this underlying property in mind. Rather, it is mired in a reductionist, linear, predictivist mentality ignorant of underlying complex system behaviors. We find ourselves, as a result, constantly befuddled when the intended benefits of environmental regulation fail to materialize or, worse, when consequences contrary to the intended effects materialize. To be sure, the coercive, regulatory, command-and-control state has produced some admirable results in terms of environmental protection,[22] but the underlying reductionist premises of that approach have exhausted their usefulness and will never allow us to tackle the significant environmental challenges ahead.

These first two themes lead to the third theme—challenging the entrenched mentality of environmental law to move beyond the popular "reinvention" rhetoric that has emerged as many policy makers have recognized the need for reform to a fully revolutionized environmental law based on the complex adaptive system model.[23] To manage the impact of human society on the inherently chaotic, adaptive environment, the environmental law system itself must possess those dynamical qualities. While many practitioners and commentators consider environmental

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21. Uniformitarianism is the philosophy of gradual change advocated by Charles Lyell in the 1830s. *See* Richard Monastersky, *The Call of Catastrophes*, 151 SCI. NEWS S20, S20 (1997). It posits that "the history of the world has been shaped by the same slow processes that can be seen today wearing away mountains or replacing one species with another. Because no one has ever witnessed a planet-wrenching impact, uniformitarians regarded such events as an outlandish explanation for past extinctions." *Id.*

22. Refer to note 202 *infra* and accompanying text (describing the success of the federal acid rain program).

23. Refer to Part IV *infra* (discussing the need to view the environment and environmental law as complex adaptive systems).

law a mess, they mean so principally in the sense that it is a top-heavy, recondite infrastructure of regulatory prescriptions designed to centralize power, divide issues into sub-sub-sub-issues, tightly manage outcomes, and thereby generally confuse every person responsible for enforcing or complying with its requirements.[24] That mess—that nonadaptive heap of prescriptive and proscriptive commandments—has cut through the kind of messiness we need in environmental law. The adaptive, dynamical, sometimes chaotic forces found in complex adaptive systems must be present if the legal system is to respond effectively and creatively to the very same qualities present in the environment and society. But the baby steps of incremental "reinvention" and the blind leap of faith into total "deregulation," the two models of reform most often advanced today,[25] are misguided responses based on outdated conceptions of law and society that conceal the complex adaptive nature of the legal system. Unless environmental law sheds its traditional premises and methods, the findings of complexity theory suggest we will not achieve the kind of environmental law system needed to confront our changing future.

Those three themes establish the premises of my ultimate argument, that a truly radical transformation of environmental law is needed. In Part III of this Article, I outline what this revolution of environmental law must entail. Five key questions, each corresponding to a quality of complex adaptive systems, must be addressed. First, what is the appropriate aggregation and distribution of environmental policy decision making entities? Second, how can the decision making process be made more nonlinear and thus more flexible? Third, how can we most efficiently and effectively promote the flow of relevant information through the environmental law system? Fourth, how can the diversity of the environmental law system, particularly the spectrum of available legal tools and outcomes, be maintained? Fifth, how can environmental law reform take place fast enough to keep up with its evolving subject matter, but nonetheless form a stable base from which legal, business, environmental, and other social institutions can operate? These questions go to the very heart of environmental law as we presently know it, and they suggest that merely tinkering at the edges will not suffice if we

24. *See* J.B. Ruhl, *Malpractice and Environmental Law: Should Environmental Law "Specialists" Be Worried?*, 33 HOUS. L. REV. 173, 180-92 (1996) (describing the complexities of environmental law and the potential malpractice threats they pose).

25. Refer to Part III.B *infra* and accompanying text (discussing the policy response of the Clinton Administration and the Republican-controlled 104th Congress).

truly wish to "reinvent" environmental law in a way that will have lasting significance.

I close the discussion in Part III with a description of the framework for redesigning the structure and schemata of environmental law that will respond to those issues in a context most amenable to allowing the complex adaptive system forces to take hold and flourish. This replacement involves nothing less than replacing the basic organizing principles of environmental law with new ones—a revolution of environmental law to its deepest roots. First, the policy must be focused on the goal of achieving long term global *sustainable development*. Second, the decision making process must be modeled around principles of *adaptive management*. Finally, the performance measurement for determining whether the process is attaining the policy must use *biological diversity* as its central standard. These concepts independently have become familiar in recent years. It is no exaggeration to portray them as the three legs of a newly emerging environmental law system. What I hope to offer to the burgeoning commentary on their shapes and uses is the exploration of the science of complex adaptive systems as a model for the integration of these three revolutionary concepts into a composite whole that will more successfully allow each to be defined and fulfilled. Only then will we be able to think of environmental law as a complex adaptive system.

II. THE SUBJECT MATTER OF ENVIRONMENTAL LAW CONSISTS OF COMPLEX ADAPTIVE SYSTEMS

Complex adaptive systems combine qualities of coherent stability and disordered change to produce sustaining, adaptive performance over the long run.[26] Five important features of complex adaptive systems explain how they are able to balance stability and change to produce this outcome. First, they perform according to complex, large-scale behaviors that emerge from the aggregate interactions of less complex agents, such as how the trends of macroeconomic scale represent the aggregate behavior of many individual firms or investors.[27] Second, the interactions of the system exhibit unpredictable, nonlinear relationships incapable of being neatly plotted as straight line formulae, as revealed in the complex dynamics of many predator-prey populations.[28] Third, the complex adaptive system can be described

26. *See* HOLLAND, *supra* note 2, at 4 (stating that a characteristic shared by complex adaptive systems is "coherence under change").

27. *See id.* at 11.

28. *See id.* at 15-23 (using mathematical equations to illustrate the complexity

through the varied flows of its mediums—fluids, money, energy, information, and so on—just as the weather reporter traces the jet stream to describe storm patterns.[29] Fourth, complex adaptive systems are defined by their diverse ingredients and context, as in how a biologist might describe the diverse species in an ecosystem.[30] Fifth, all four of these properties combine into self-organizing critical state behavior through which change is transformed into a stabilizing rather than disrupting force.[31] The complex adaptive system thus operates in a state of ordered disorder, primed to adapt to external forces and to evolve with, rather than separate from, its environment.

Not surprisingly, after almost two decades of developing the model of complex adaptive systems, some researchers believe these systems are found throughout nature (*e.g.*, the weather, ecosystems, earthquakes, genetics, and evolution) and throughout human organizational behavior (*e.g.*, in economic activity, politics, and technological development).[32] This model has profound implications for environmental law, which is about regulating human behavior on behalf of nature. The subject matter of environmental law, in other words, consists of complex adaptive systems, and hence it behooves environmental policy decision makers to examine what the science of complex adaptive systems has to say about how such systems behave, evolve, and co-evolve.

A. The General Properties of Complex Adaptive Systems

The basic research instrument of complexity theory is the high-speed computer which allows us to study natural and human systems as no other tool ever has.[33] The systems under study have not changed much in centuries—the weather, the solar system, economies, ecosystems, and so on—but our understanding

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in this seemingly simple interrelation).

29. *See id.* at 23-27

30. *See id.* at 27-31.

31. Refer to Part II.A.5 *infra* (noting the self critical behavior of complex adaptive systems).

32. *See, e.g.*, PER BAK, HOW NATURE WORKS 9-32 (1996) (discussing the evidence of complex adaptive behavior in sandpiles, biological evolution, ecosystems, earthquakes, and brain functions). The underlying premise of complexity theory is that "similar patterns of activity can arise in systems that differ greatly from one another in their composition and in the nature of their parts .... They all show similar types of dynamic activity—rhythms, waves that propagate in concentric circles or spirals that annihilate when they collide, and chaotic behavior." GOODWIN, *supra* note 8, at 77.

33. *See* CASTI, WOULD-BE WORLDS, *supra* note 11, at 35 (relating that affordable, high-quality computing systems allow us to construct theories of complex physical, social, biological, and behavioral processes).

of those systems has changed dramatically as a result of advancements in the tools of study.[34] The telescope, for example, radically altered our perception of the heavens as a system.[35] High-speed computers have done so for all systems, as they have allowed us even to conjure up the image of complex adaptive behavior as a property of systems we have been studying for eons. And the implications of this new way of viewing systems are not merely superficial. It may be too soon to tell whether complexity theory represents a scientific revolution in the Kuhnian sense,[36] but it is not too soon to say that complexity theory, despite its detractors, has pushed its way into the forefront of research in virtually every field of physical and social science.[37] Although much of that research and its literature are presented in technical terms,[38] the unquestionable essence of the work is the development of a new *theoretical* understanding of how the world behaves. That theory can be summarized through the description of five key behavioral qualities.[39]

34. *See id.*

35. *See* A. C. CROMBIE, AUGUSTINE TO GALILEO 275 (1953) (explaining that many important aspects of the scientific revolution were carried through before the invention of the telescope which later became indispensable).

36. Thomas S. Kuhn is credited by most historians of science as developing the benchmark theory of the criteria by which new scientific theories are measured in terms of their transformative effect on science in general. *See* THOMAS S. KUHN, THE STRUCTURE OF SCIENTIFIC REVOLUTIONS (1962).

37. For example, in his recent and much-heralded overview of the current state of science, science historian John Horgan postulated that science is increasingly diminishing in its importance to human progress and questioned whether complexity theory could reverse that trend. Nevertheless, he devoted two full chapters and parts of several others to a discussion of complexity theory. *See* JOHN HORGAN, THE END OF SCIENCE (1996). Social scientists have gravitated to complexity theory as well. *See generally* CHAOS, COMPLEXITY, AND SOCIOLOGY (Raymond A. Eve et al. eds., 1997) (providing an extensive discussion of complexity theory applications in various sociological contexts).

38. As an example, look at any copy of the journal *Complexity*.

39. For a brief explanation of these qualities and how they can be used to evaluate mediation, see J.B. Ruhl, *Thinking of Mediation as a Complex Adaptive System*, 1997 BYU L. REV. 777. Many readers will be familiar with some of the technical concepts used in complexity theory to describe complex adaptive system structure and dynamics, such as phase space, trajectory, strange attractors, sensitivity, fractals, and so on. Elsewhere, I have outlined how those concepts provide a theoretical foundation for applying complexity theory to sociolegal structure and dynamics in general. *See* Ruhl, *Complexity Theory as a Paradigm*, *supra* note 15, at 927 (observing that law and society interact in a nonlinear dynamical manner similar to that which scientists have observed in other natural and social systems). In this Article, I assume that those foundational structures are present, and I am concerned principally with describing the behavioral qualities they produce and with applying them in specific sociolegal settings. The distinction might be thought of as being between theory and application.

1. Aggregation. By limiting observation to an individual ant—its foraging, building, defending, and so on—it is highly unlikely the observer could accurately predict the behavior of the ant colony.[40] The ant colony, unlike an individual ant, is highly adaptive, surviving over time periods far in excess of individual ant lives and in the face of a variety of environmental hazards, any one of which poses death to individual ants. This pattern of adaptive collective behavior emerging from the interconnected parts is found throughout nature and human society.[41]

Even when the individual parts of a system are unaware of or indifferent to their mutual effects or are even working against each other, emergent collective behavior may become highly adaptive and, we can only hope, beneficial to the collective whole. Research has suggested that the magnitude and direction of this effect depend on the number of decision making components, or patches as they are known in the complex adaptive systems literature,[42] and how tightly intertwined, or "coupled," are their decision making processes.[43] The problem is that for a multi-patch, coupled decision making system, there is no reliable way to predict, simply on the basis of observation of any of the system's individual patches, what form the system's emergent behaviors

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40. *See* HOLLAND, *supra* note 2, at 11 (observing that while an individual ant is weak, an ant colony is strong and highly adaptive).

41. Emergence is "a process that leads to the appearance of structure not directly described by the defining constraints and instantaneous forces that control a system." James P. Crutchfield, *Is Anything Ever New?: Considering Emergence, in* COMPLEXITY: METAPHORS, MODELS, AND REALITY at 515, 516 (George A. Cowan et al. eds., 1994). Cohen and Stewart explain that the key to understanding why emergence occurs lies in the number of system components and their interaction; with increasing numbers of system components, eventually the sum effect of the interactions between the components becomes a dominating characteristic of the system. *See* COHEN & STEWART, *supra* note 8, at 182. The result is that

> if the effect of any particular interaction is tiny, we may not be able to work out what it is. We can't study it on its own, in a reductionist manner, because it's too small; but we can't study it as part of the overall system, because we can't separate it from all the other interactions.

Id.

42. *See* KAUFFMAN, AT HOME IN THE UNIVERSE, *supra* note 8, at 247 (observing that breaking an organization into "patches" where each patch acts in its own self interest, even if it is harmful to the whole, sometimes leads to the welfare of the whole organization).

43. *See id.* at 252-53 (summarizing the patch procedure which requires dividing a difficult task with interacting parts into nonoverlapping patches; as each patch optimizes within itself, the problem to be solved by the other patches is altered). The study of interconnected systems is a major research focus of complexity theory. The general model is of so-called *NK* systems, where *N* is the number of system components (patches) and *K* is the number of inputs from other components that each component needs in order to know what to do next in the system (coupling). By constructing computer models of *NK* systems, complexity theory researchers can study the effects of altering *N* and *K* in different combinations. *See id.* at 172-73.

might take and to what end. You have to let the whole system run to see what happens.[44]

2. Nonlinearity. If we were to study the relationship between a population of foxes and one of rabbits living in the same ecosystem, a reasonable starting proposition might be that as the fox population increases the rabbit population will drop. Over time, however, a declining rabbit population will fail to support an increasing fox population, and foxes will begin to decline. Eventually, rabbits might bounce back, allowing foxes to increase in number again, and so on. Add hawks and mice into the picture and soon it becomes very difficult to predict what any species population will be, based on the figures available in the present for the other species. The relationships between the predator and prey species populations have become nonlinear.[45]

Nonlinearity means that the relationships of system components we wish to measure, even though they may be deterministically related, do not exhibit mathematical proportionality.[46] Indeed, despite the neat and orderly world implied by classical mathematics and science, most of the world is governed by nonlinearity and its inherent unpredictability. This so-called deterministic randomness of nonlinearity is the behavioral trait known in complexity theory as chaos.[47] A system exhibiting such

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44. *See id.* at 288-89 (noting that "formal undecidability" means that we cannot predict certain things). This "incompressibility" of the evolution of complex adaptive systems that is inherent in the chaotic behavior is a necessary component if the system is to be adaptive. In other words, "[t]here is no faster way of finding out how a chaotic system will evolve than to watch its evolution. The dynamical system itself is its own fastest computer." Roderick V. Jensen, *Classical Chaos*, 75 AM. SCIENTIST 168, 179 (1987).

45. *See* HOLLAND, *supra* note 2, at 16-18 (providing a lynx-hare model to demonstrate the nonlinear relationship between predator and prey).

46. A system is described as linear when the relationship of the agents' interactions can be described in strictly proportional terms (*e.g.*, $y = 2x + 3z$). A system is nonlinear, therefore, if the relationships of the agents represents a function in which the output of an element is not proportional to its input. *See* P.G. DRAZIN, NONLINEAR SYSTEMS 1 (1992) (stating that a nonlinear system represents a feedback loop in which an element's output is not proportionate to its input).

47. Chaos behavior thus has been described as "order *masquerading* as randomness." GLEICK, *supra* note 11, at 22. Classic examples of chaos in physical systems run by deterministic rules are the erratic dripping patterns from water faucets and the motion of a pinball. *See* Tom Mullin, *Turbulent Times for Fluids*, *in* EXPLORING CHAOS 59 (Nina Hall ed., 1991); Ian Percival, *Chaos: A Science for the Real World*, *in* EXPLORING CHAOS 11 (Nina Hall ed., 1991). Although the rules determining the presence of chaos in such systems may be simple and rigid, the randomness of the system's behavior prevents easy discovery of all the rules merely by observation of the behavior. Thus, chaotic behavior "only looks complicated because you don't know what the rule is." COHEN & STEWART, *supra* note 8, at 197. More to the point, even if you did know what the rule is, thus making the system computable, you couldn't predict what will happen very far into the future.

chaotic behavior is extremely sensitive to the environmental conditions in which the system exists. This property, known as sensitivity, means that two similar systems found at one time to be located at very close points can later be found to have diverged from one another wildly.[48] Chaotic systems thus have a propensity to experience an arbitrarily large divergence in behavior based on arbitrarily small changes in system variables, making prediction of the system's future course very difficult, if not impossible in the true sense of the word.

Although the lack of predictability is a nagging aspect of complex adaptive systems, researchers have found that the most robust systems are those which manage to stay balanced between extreme order and extreme chaos.[49] While nonlinearity may be a nuisance for purposes of predicting system behavior, it is precisely the ability to bend and to avoid being locked into rigidly linear behavior that allows complex adaptive systems to adapt to changing circumstances.[50] In a sense, these systems are drawing as much as possible from the adaptive qualities of nonlinearity without falling all the way into disaster. They are being held back from the edge by the presence of ordered, linear behavioral qualities in the system. A system poised in this manner "at the edge of chaos" is likely to be adaptive and successful—in other words, a complex adaptive system.[51]

3. Flows. Generally speaking, the force of change in complex adaptive systems—what makes them dynamical—involves a flow of some medium.[52] In an economy, for example, money and the factors of production move throughout the system from component to component. When such flows take place in

48. *See* CASTI, COMPLEXIFICATION, *supra* note 8, at 91-92.

49. Thus, "complex systems constructed such that they are poised on the boundary between order and chaos are the ones best able to adapt by mutation and selection. Such poised systems appear to be best able to coordinate complex, flexible behavior and best able to respond to changes in their environment." KAUFFMAN, ORIGINS OF ORDER, *supra* note 8, at 29. Most long-lived evolutionary systems thus are inherently unpredictable because they are designed to adapt to the inherent unpredictability of their environment. *See* Peter Schuster, *How Does Complexity Arise in Evolution*, COMPLEXITY, Sept.-Oct. 1996, at 22, 22 (describing unpredictability as an integral force in biological evolution).

50. *See* KAUFFMAN, ORIGINS OF ORDER, *supra* note 8, at 29 (stating that complex systems poised between order and chaos may adapt by mutation and selection).

51. *See* HOLLAND, *supra* note 2, at 4 (observing that complex adaptive systems share the common characteristic of coherence under change). Some theorists call the complex behavior region the "edge of chaos." KAUFFMAN, ORIGINS OF ORDER, *supra* note 8, at 31.

52. A nonlinear system is considered dynamical if the (nonproportional) relationships of the agents evolve with time or with some variable like time. *See* DRAZIN, *supra* note 46, at 1.

the context of complex adaptive systems experiencing aggregation and nonlinearity, the flows themselves exhibit complex, circuitous paths known as feedback loops.[53] The multiplier effect in economic theory, for example, explains how money transferred at one stage of a series of transactions moves from stage to stage and amplifies the effect of the initial transfer.[54] Such feedback loops can become exponential in effect and thus dominate the system in which they operate.[55]

These and similar relationships tend to be dissipative in that they work in one direction but not in the other.[56] If the flows are reversed, it is not possible for the system components in a complex adaptive system simply to retrace their steps. New feedback loops may emerge, the old ones may change strength or direction, and new possibilities for the system open up. Hence, complex adaptive systems depend on their flow patterns to provide the momentum that both strengthens and regularizes the aggregation and nonlinearity effects, thus enhancing long term adaptiveness.

4. Diversity. A single tree in a tropical rainforest ecosystem can harbor over ten thousand distinct species of insects, and it is possible to walk long distances in the rainforest without twice encountering the same species of tree.[57] Diversity of such

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53. Adaptation is associated with the feedback and feedforward loops made possible by multiple paths of interactions between system components and thus "is an emergent property which spontaneously arises through the interaction of simple components." GLEICK, *supra* note 11, at 339. Loops of this kind allow the system to "restructure, or at least modify, the interaction pattern among its variables." CASTI, COMPLEXIFICATION, *supra* note 8, at 271.

54. *See* HOLLAND, *supra* note 2, at 23-27, 84-87.

55. *See* Douglas S. Robertson & Michael C. Grant, *Feedback and Chaos in Darwinian Evolution*, COMPLEXITY, Sept.-Oct. 1996, at 10, 12-14.

56. The Belgian Nobel laureate Ilya Prigogine defined a dissipative system as one for which the driving force is the nonequilibrium flux of matter and energy through the system that increases order and sustainability in the system but makes reversing the system impossible. *See* Tony Rothman, *Irreversible Differences*, THE SCIENCES, July-Aug. 1997, at 26, 29-31 (discussing the implications of Prigogine's theory for theories of time and space). Because these systems experience nonequilibrium in terms of input, they necessarily cannot be "reversed" so as to replicate the conditions of the system at a prior point in time. *See* KAUFFMAN, AT HOME IN THE UNIVERSE, *supra* note 8, at 23 (observing that small changes in initial conditions often lead to profound changes in a chaotic system and stating that, for this reason, it is often impossible to discern the initial conditions). For example, suppose that Company A is ordered to compensate Company B for illegal overcharges, that is, reversing the flow of money between the two entities. The economic impacts associated with the multiplier effect that occurred when Company B first paid Company A, such as payments Company A made to its vendors and employees with the proceeds of Company B's payment, do not also unwind to their original state. Rather, a new multiplier effect occurs, and the system reaches a new state.

57. *See* HOLLAND, *supra* note 2, at 27.

magnitude is the signature of complex adaptive systems.[58] As diversity increases, each component of the system becomes less able to duplicate the whole and more resigned to relating to other system components through its particularized niche.[59] Through competition and cooperation, niches become increasingly differentiated, and the number of different niches grows.[60] The diversification of components in turn adds to the emergent effects of aggregation, makes system nonlinearity even more unpredictable, and opens the door to more complicated and far ranging flows and feedback loops.[61] Because more is possible in such a system, more is done, more efficiently, than in simpler systems.[62]

At this stage the system as a whole depends on no single component for its long term sustainability. Thus, difficult choices have to be made as to the overall structure of the system—should it favor the traits of this component, or of that component; should there be more of these components, or of those components; and so on. Complexity theory research suggests that within any complex adaptive system there exist "conflicting constraints" between different possible combinations of components' structural traits.[63] These constraints limit the degree to which any one trait can be adjusted without causing failure or degradation of another constraint.[64] In considering how it should be

58. *See id.* (discussing the inherent diversity in complex adaptive systems).

59. *See* HOLLAND, *supra* note 2, at 27 (stating that in a diverse system each agent fills a particular niche and if any agent is removed from the system, the system will adapt until a new agent is found to occupy the hole).

60. *See* KAUFFMAN, AT HOME IN THE UNIVERSE, *supra* note 8, at 282-83 (using the example of how production and consumption complement and substitute the niches of an economic web).

61. *See id.* at 296-97 (stating that diversity leads to more diversity, which leads to complexity).

62. *See* F. Stuart Chapin III et al., *Biotic Control over the Functioning of Ecosystems*, 277 SCIENCE 500, 500 (1997) (observing that a diverse environment provides opportunities for more efficient use of resources).

63. *See* KAUFFMAN, AT HOME IN THE UNIVERSE, *supra* note 8, at 169-73 (using a model of a genoic network to show that the more interconnected genes are, the more likely it is that conflicting constraints will exist).

64. The exoskeleton of an ant, for example, presents tremendous advantages for the size of an ant, but if ant size were to increase, eventually the proportional weight of the exoskeleton would result in the ant's demise. As Kauffman explains:

> Here is the problem: in a fixed environment, the contribution of one trait—say, short versus long nose—to the organism's fitness might depend on other traits—for example, bowed versus straight legs. Perhaps having a short nose is very useful if one is also bowlegged, but a short nose is harmful if one is straight legged . . . .
>
> In short, the contribution to overall fitness of the organism of one state of one trait may depend in very complex ways on the states of many other traits.

Id. at 170. For a more extensive analysis of how conflicting constraints emerge from structured, therefore, the system has to evaluate the effects of changing one trait based on the overall effects on fitness by taking all other traits into consideration. Thus, we can envision a landscape of varying fitness level potentials for the system in a given environment with the peaks, valleys, and plains of the landscape representing the fitness potential of different combinations of system structures.[65] Indeed, we can construct such a fitness landscape for any system of connected interactions. The presence of such conflicting constraints will make the landscape flat or rugged and multipeaked—a fitness landscape.[66]

The fitness landscape metaphor improves our understanding of how systems use aggregation, nonlinearity, flows, and diversity to evolve. The objective of adaptive change in the system is to stay on the high parts of this landscape in the face of outside disturbances.[67] The mechanics of moving over the landscape, therefore, are of great interest to the system. The system might "walk" across the landscape through gradual, incremental testing of altered variable combinations, hoping to find a higher spot.[68] But that mode of travel is slow and prevents the system from quickly testing faraway points in the hope of finding peaks significantly higher than those available in the nearby landscape.[69] In other words, the system might find a way to "jump" across the landscape at greater distances, as risky as that might be.[70] Indeed, by tapping into the dynamic forces of the system,

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the diversity property of the legal system to form a fitness landscape for sociolegal evolution, see Ruhl, *Fitness of Law*, *supra* note 15, at 1448-56.

65. *See* KAUFFMAN, AT HOME IN THE UNIVERSE, *supra* note 8, at 26 (relating that biologists envision "fitness landscapes, where the peaks represent high fitness, and populations wander . . . across the landscape seeking peaks, but perhaps never achieving them").

66. In the field of evolutionary biology, for example, Kauffman states that

> [a]daptation is usually thought of as a process of "hill climbing" through minor variations toward "peaks" of high fitness on a fitness landscape. And natural selection is thought of as "pulling" an adapting population towards such peaks. We can imagine a mountain range on which populations of organisms . . . are feeling their way to the summits.

Id. at 154.

67. *See id.* at 27 (describing a fitter organism as being higher on the fitness landscape).

68. The rules of the "adaptive walk" are simple. Start from wherever the species is on its fitness landscape and consider the fitness level that results when a randomly chosen gene is altered. If it is a fitter level, go there; if it is not a fitter level, try again. *See id.* at 166.

69. *See id.* at 167 (stating that searching for fitness peaks through adaptive walks is not an efficient way of searching).

70. *See id.* at 193 (describing how simultaneously making a large number of mutations allows organisms to take long jumps across the fitness landscape and that the fitness value the organism lands on will be totally random with respect to the

which can trigger large shifts in the system behavior based on small changes in system variables, a very long jump may indeed be possible, though its destination will be unpredictable.[71] Thus, diversity, which defines the terrain of the fitness landscape, is the driving force behind evolutionary success in complex adaptive systems.

5. Self-Criticality. Successful complex adaptive systems are constantly changing to maintain adaptability, but they also exhibit a stability of basic structure in the face of externally caused stress. How do they manage to achieve this state of stable nonequilibrium? Some complexity theory researchers believe they have found the answer in what is known as self-organized criticality or self-critical behavior.[72] Simply put, self-critical behavior is a means of relieving system stress by integrating small local "avalanches" into the regular system behavior rather than waiting for the big crash to do the job across a larger span of the system—the way an area of tectonic activity might produce thousands of small tremors in order to avoid a severe earthquake.[73] Systems thus regulate complexity of structure

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fitness value from which the organism began).

71. Such events in nature are often known as accidents. The power of accident—that is, of the chaos, emergence, and catastrophe that small accidents can unleash—should not be underestimated. Starting at the small level and working up, it seems clear that

> the space of possible molecules is vaster than the number of atoms in the universe. Once this is true, it is evident that the actual molecules in the biosphere are a tiny fraction of the space of the possible. Almost certainly, then, the molecules we see are to some extent the results of historical accidents in this history of life.

Id. at 186. For example, many evolutionary biologists believe that "sex has evolved . . . to permit genetic recombination. And recombination provides a kind of approximation to a God's-eye view of . . . large-scale features of fitness landscapes." *Id.* at 180.

72. For a more extensive analysis of the role of self-critical behavior and diminishing returns in the sociolegal system generally, see Ruhl & Ruhl, *Arrow of Law, supra* note 15, at 470-77.

73. Self-organized criticality is "[a] generic pattern of self-organized nonequilibrium behavior in which there are characteristic long-range temporal and spatial regularities." COVENEY & HIGHFIELD, *supra* note 8, at 432. Thus a complex adaptive system "can be locally stressed to a critical state. When the critical threshold is exceeded, the stress is distributed to the neighborhood around the locale. This can, in turn, lead to further critical thresholds in the neighboring locations thereby propagating the disturbance." Dale R. Lockwood & Jeffrey A. Lockwood, *Evidence of Self-Organized Criticality in Insect Populations*, COMPLEXITY, Mar.-Apr. 1997, at 49, 49.

The classic example is provided by physicist Per Bak, who is credited as being the founder of the hypothesis:

> We are to picture a table. Above, rather like the hand of God outstretched toward Adam's on the ceiling of the Sistine Chapel, a hand is poised, holding

either by avoiding it in the first place—not a particularly adaptive strategy—or by shedding it in small, frequent doses when needed to avoid buildup of unmanageable stress levels.

Of course, earthquakes do happen. Even in the self-critical state, a complex adaptive system will occasionally experience major disruptions inherent in nonlinearity and aggregation.[74] Change is constant, displayed in high frequencies of small fluctuations, punctuated by the occasional large shifts in system conditions. In other words, there is only a course of "punctuated equilibrium" in which periods of equilibrium are simply periods of incremental change surrounded by catastrophic events.[75] Indeed, the disturbances caused by the major change events are necessary to maintain system diversity, as they disrupt the established "equilibrium" and make room for new system components and arrangements.[76]

Self-critical behavior is also a manifestation of the fact that improvements in system fitness come with diminishing returns.[77]

> sand. Sand slips persistently from the hand onto the table, piling higher and higher until the heap of sand slides in avalanches from the top of the table onto a distant floor.
>
> Piling higher, then reaching its rest angle, the sandpile achieves a rough stationary state. As the sand is trickled onto the pile, many small sandslides avalanche down the sides, and a few large sandslides, ... We have noted before, if one plots these avalanches, one finds our new familiar power-law distribution.

KAUFFMAN, AT HOME IN THE UNIVERSE, *supra* note 8, at 235-36. *See generally* Fred Guterl, *Riddles in the Sand*, DISCOVER, Nov. 1996, at 104, 108-14 (describing current research on Bak's theory and on the unexplained behavior of sand generally); I. Peterson, *Shaken Bead Beds Show Pimples and Dimples*, 150 SCI. NEWS 135, 135 (1996) (describing new research method for studying granular flow). Bak has posited how this principle might apply to earthquakes, clouds, solar flares, biological evolution, and economies, and posits that it is a necessary feature for integration of any system component into a highly complex system. *See generally* BAK, *supra* note 32, at 86-190; Per Bak, *Self-Organized Criticality: A Holistic View of Nature*, *in* COMPLEXITY: METAPHORS, MODELS, AND REALITY at 477, 477-96 (George A. Cowan et al. eds., 1994).

74. *See* KAUFFMAN, AT HOME IN THE UNIVERSE, *supra* note 8, at 236 (positing that physical, biological, and perhaps even economic worlds may exhibit self-organized criticality by considering the example that even the size distribution of earth quakes is a composite of small quakes and a few large ones).

75. For a further discussion of punctuated equilibrium theory as it emerged in paleontology, see Ruhl, *Fitness of Law*, *supra* note 15, at 1428-30. A variation of the theory focuses on the "coordinated stasis" found in the paleontological records, of which there is mounting evidence. *See Does Evolutionary History Take Million-Year Breaks?*, 278 SCIENCE 576 (1997).

76. Today ecologists are confirming that large disturbances such as fires and floods can promote ecosystem diversity. *See* Seth R. Reice, *Nonequilibrium Determinants of Biological Community Structure*, 82 AM. SCIENTIST 424, 430 (1994). Thus, human efforts to suppress those catastrophes have contributed to diminishing biodiversity over time. *See id.* at 424.

77. *See* KAUFFMAN, AT HOME IN THE UNIVERSE, *supra* note 8, at 236

As fitness increases, the effort required to improve fitness in additional increments also increases.[78] The drive toward higher fitness thus becomes self-defeating after a point, and it makes sense for the system to lop off some of the infrastructure it is using in search of higher fitness in order to preserve energy needed for responding to changing conditions. Therefore, the reality of complex adaptive systems is that they are usually quite average in performance over any short term horizon; their virtue is in sustaining that level of performance over the long term.[79] It is entirely possible, indeed probable, that for any fixed environment the system design best suited for withstanding adverse conditions—the maximally "fit" system—will be one which is either highly ordered or highly chaotic—that is *not* a complex adaptive system. The problem is that over time environmental conditions change, and if the system designed for one set of conditions cannot adapt to those changes, what were once the fittest qualities may become liabilities.[80] To borrow a phrase, by designing the maximally fit system for the moment, you can wind up winning the battle but losing the war.

B. Examples of Complex Adaptive Systems in the Subject Matter of Environmental Law

At the time of the first major international conference on the environment in Stockholm in 1972, there had been almost no mention in scientific or legal literature of what are among the front-runners of environmental policy focus today: global warming, acid

(indicating that every step taken toward higher fitness decreases the number of paths leading toward still higher fitness).

78. This interrelation is an inherent feature of an adaptive walk across a correlated fitness landscape in that "with every step one takes uphill, the number of directions leading higher is cut by a constant fraction, . . . so it becomes ever harder to keep improving." *Id.* at 178. Kauffman explains that "[a] very simple law governs such long-jump adaptation[s]. The result, exactly mimicking adaptive walks via fitter single-mutant variants on random landscapes is this: every time one finds a fitter long-jump variant, the expected number of tries to find a *still better* long-jump variant doubles!" *Id.* at 193. Thus, "[a]s this exponential slowing of the ease and rate of finding distant fitter variants occurs, then it becomes easier to find fitter variants on the local hills nearby." *Id.* at 195. The rule of thumb, therefore, is that "[a]s fitness increases, search closer to home. On a correlated landscape, nearby positions have similar fitnesses. Distant positions can have fitnesses very much higher and very much lower. Thus optimal search distance is high when fitness is low and decreases as fitness increases." *Id.* at 196.

79. *See id.* at 224-35.

80. Thus, "[t]he self-organized critical state with all its fluctuations is not the best possible state, but it is the best state that is dynamically achievable." BAK, *supra* note 32, at 198.

rain, and tropical deforestation.[81] Did these problems arise suddenly? How did they escape our detection until recently? What will the next problem be?

It is not clear that asking these questions, much less attempting to answer them, is a useful exercise. Environmental processes, including how the environment responds to human insults, have a tremendous capacity to generate significant problems for society and to take us by surprise despite our intensive efforts to study and predict them.[82] To be sure, we perceive abundant regularities in the environment—the sun rises in the east, grass is green, seasons change—but even these we see as constants only because changes in them occur over scales of time that are not relevant to human perception. The rule of thumb for the relevant scales of time and space, however, is one of continuous, perceptible, unpredictable changes across many environmental parameters. This is because environmental processes and social influences on environmental processes are run by the rules of complex adaptive systems. In other words, the subject matter of environmental law and policy is a mess.

At the risk of appearing reductionist and thus omitting important dynamics, the previous point can be demonstrated by focusing on several of the important components of the human-environment system: ecosystems, technology, economies, and land use. Ecosystems represent a natural system, technology represents a human-designed physical system, and economies represent a human activity system.[83] Land use is the intersection of all three—the use of technology directed by economic forces to convert natural ecosystems to human uses. Each of these is a complex adaptive system in its own right. Together, along with many other social and natural phenomena, they form a set of coevolving systems that defy our complete understanding.

1. Ecosystems. Biological evolution is one of the most studied topics in science, and yet the amount we do not know about evolution far exceeds the amount we do know. The part we do not even begin to understand is associated with the

81. *See* Norman Myers, *Environmental Unknowns*, 269 SCIENCE 358, 358 (1995).

82. *See* Michael P. Collier et al., *Experimental Flooding in Grand Canyon*, SCI. AM., Jan. 1997, at 82, 82-83 (reporting how a planned flood had the surprising effect of creating a beach).

83. *See* CLAYTON & RADCLIFFE, *supra* note 14, at 21 (grouping systems into five categories: (1) natural systems; (2) designed physical systems; (3) designed abstract systems; (4) human activity systems; and (5) transcendental systems). For purposes of the analysis here, I do not consider the category of transcendental systems as it is beyond our knowledge. The category of human-designed abstract systems is represented, of course, by law itself.

contribution ecological forces make to evolutionary dynamics. As the eminent biologist Edward O. Wilson puts it, "[w]hat we understand best about evolution is mostly genetic, and what we understand least is mostly ecological. . . . [T]he major remaining questions of evolutionary biology are ecological rather than genetic in content."[84]

The emergence in environmental biology of the concept of ecosystems as unpredictable, dynamically changing systems has injected a heightened awareness of the role of indeterminacy and randomness into evolutionary theory.[85] The mix of species in an ecosystem depends largely on the timing of introduction and the location.[86] But how are the assembly rules[87] for an ecosystem determined,

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84. EDWARD O. WILSON, THE DIVERSITY OF LIFE 93 (1992). *See also* Michael T. Madigan & Barry L. Marrs, *Extremophiles*, SCI. AM., Apr. 1997, at 82, 82 (reporting the discovery of a new branch of life found in extreme ecological conditions); Richard Monastersky, *Out of Arid Africa: Debate Heats Up on Whether Climate Change Sparks Evolutionary Outbursts*, 150 SCI. NEWS 74, 74-75 (1996) (discussing whether climate changes instigate evolutionary changes); Taylor, *supra* note 6, at 52 (noting that "[a]t present . . . the structure and dynamics of this ecological context have not been well integrated into evolutionary theory").

85. As the geneticist John Holland has observed about ecosystems, "the whole is more than the sum of its parts. Even when we have a catalog of the activities of most of the participating species, we are far from understanding the effect of changes in the ecosystem." HOLLAND, *supra* note 2, at 3. *See also* COHEN & STEWART, *supra* note 8, at 367 (comparing an ecosystem to a river that constantly changes because one never steps in the same water twice). The past 30 years of research in biology have spawned a "new paradigm of ecology, mothballing the old notion of a 'balance of nature' and unveiling a vibrant new replacement focusing on flux." William Stolzenburg, *Building a Better Refuge*, NATURE CONSERVANCY, Jan.-Feb. 1996, at 18, 21. The new focus on dynamic change has led scientists to reevaluate the premises upon which many legal and policy decisions have been based, such as the size, location, and operation of wildlife refuges. *See id.*

86. For example, in the phenomenon known as adaptive radiation, ecosystem conditions determined the variety of finch species on the Galapagos Islands and the cichlids of Lake Victoria. *See* WEINER, *supra* note 6, at 207-08; WILSON, *supra* note 84, at 106-08. In these cases, one or very few ancestral species that originally colonized the habitat have since then radiated into many species that now fill almost all the usual niches of birds, in the case of the Galapagos finches, or freshwater fish, in the case of the cichlids. *See* WILSON, *supra* note 84, at 101-04, 107 (discussing how the various niches were filled by the Galapagos finches and how the cichlids fill almost all niches available to freshwater fish). Had those niches already been filled by other species, evolution would have taken a different course. *See id.* at 96 (observing that when a few species split and massively respond to an opportunity, they and their descendants seize a large portion of the environment and hold it thereafter). Similarly, convergence is "the increasing similarity during evolution of two or more unrelated species." *Id.* at 395. For example, in ecosystems around the world that lack true woodpeckers, such as some recently (in geological time) formed islands, adaptive radiations of the bird species which originally colonized the ecosystems have led to evolutionary convergence of different new species towards the woodpecker niche. *See id.* at 98-101.

87. Wilson explains that "[a]ssembly rules determine which species can coexist in a community of organisms (such as the bird species occupying a forest patch). The rules also determine the sequence in which species are able to colonize the habitat." WILSON, *supra* note 84, at 171. Some complex adaptive systems researchers are de-

and how do they contribute to evolution of species across time? These are the questions of the future for evolutionary biologists.

Questions about ecosystems not only are relevant to evolutionary biologists, but also go to the heart of environmental law and policy at all levels. Here again, we find that we know less than we do not know, but we do know the following:

> *1. The connections between species within an ecosystem are often poorly understood,*[88] *or understood too late to do any good.*[89]
>
> *2. Little is known, particularly for large carnivores, about how much habitat and how many species individuals are needed to support a species as a long-term viable population.*[90]
>
> *3. One of the most pernicious and least understood threats to ecosystems involves the "invasion," often unwittingly assisted by human activities, by particularly adaptable species that prey upon or out-compete the "native" species of the ecosystem.*[91]

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voting considerable effort to investigating the complex factors that lead to discrete assemblages of co-adapted species. *See Works in Progress: Ecological Discontinuities*, SFI BULLETIN, Summer 1997, at 13, 13.

88. The extinct dodo, for example, is now believed to have had a mutualistic relationship with the endangered tambalacoque tree: the tree's seed evolved to resist crushing in a dodo's gizzard, resulting in a pit too thick to germinate without abrasion of its outer wall. *See* Sally Valdes-Cogliano, *A Lost Piece of the Puzzle*, ENDANGERED SPECIES BULL., Nov.-Dec. 1996, at 11, 11. But, while passing through the birds' system, the seeds underwent sufficient abrasion to promote germination once expelled from the bird. *See id.* The dodo's extinction over 300 years ago only recently was identified as a major cause of the tree's decline. *See id.* Now that the connection is understood, the tree's seed can be germinated artificially. *See id.*

89. For instance, researchers have determined that the life cycle of most native freshwater mussel species in American rivers includes a brief stage as a benign parasite on specific host species of fish who help disperse the mussels upstream. *See* Richard J. Neves, *The Mussel/Fish Connection*, ENDANGERED SPECIES BULL., Nov.-Dec. 1996, at 12, 12. Little is known, however, about which mussel species are paired with which fish species, and as freshwater fish diversity in aquatic ecosystems declines, researchers are finding it difficult to predict which species of mussels also will decline. *See id.* at 13.

90. For example, a single wolverine may travel 60 miles in one day; a Rocky Mountain wolf pack uses about 500 square miles as its home base; and a population of 1,000 grizzly bears might require an area 20 times larger than Yellowstone National Park. *See* William Stolzenburg, *The Jaguar's Umbrella*, NATURE CONSERVANCY, Mar.-Apr. 1997, at 8, 9.

91. For example, the zebra mussel, which entered North American waters in the ballast of ships, has disrupted the algae and nutrient components of many ecosystems on its way to becoming a dominant mollusk species. *See* Peter M. Vitousek et al., *Biological Invasions as Global Environmental Change*, 84 AM. SCIENTIST 468, 468 (1996). Additionally, the introduction of brook and rainbow trout and other sport fish in many aquatic ecosystems has reduced native invertebrate and amphibian populations. *See id.* at 472. Likewise, in a classic positive feedback loop, the intro-

4. Evidence of more direct adverse effects of human activities on ecosystems is abundant but difficult to understand in terms of causal effect, source of the problem, and possible solution.[92]

5. It cannot be assumed that human influence always presents a negative for ecosystem dynamics.[93]

6. Human efforts to conserve species may sometimes actually do more damage to ecosystems than good.[94]

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duction of African and Asian grasses that promote and resist fire has increased the intensity and frequency of fires and completely transformed the vegetative mix in many Australian and American grasslands. *See id.* at 474-75. Many such invasions are brought about as unintended consequences of human efforts to control pests with introduced predators. *See, e.g.*, S.M. Louda, *Ecological Effects of an Insect Introduced for the Biological Control of Weeds*, 277 SCIENCE 1088, 1088 (1997); *Biological Noncontrol*, SCI. AM., Nov. 1997, at 36, 36. There is some evidence that invasion occurs without human intervention simply as a result of the diversity of ecosystems that makes them attractive to "outsiders." *See* Jocelyn Kaiser & Richard Gallagher, *How Humans and Nature Influence Ecosystems: Does Diversity Lure Invaders?*, 277 SCIENCE 1204, 1204 (1997).

92. For example, recently a cyberspace conference was held in which researchers exchanged papers and hypotheses, with no clear consensus, regarding the increase in amphibian deformities that has been experienced around the world. *See* Sasha Nemecek, *Amphibians On-line*, SCI. AM., Mar. 1997, at 18, 18. Possible explanations offered included parasitic flatworms, water pollution, and increased ultraviolet radiation. *See id. See generally* William Stolzenburg, *The Naked Frog*, NATURE CONSERVANCY, Sept.-Oct. 1997, at 24 (tracking the status of the Ramsey Canyon leopard frog); *Study by NIEHS Says Frog Deformities Could Be Linked To Water Pollution*, 28 Env't Rep. (BNA) 1038, 1038 (1997). The United States Geological Survey has launched a North American Reporting Center for Amphibian Malformations to track hot spots of this phenomenon. *See Seen Any Deformed Frogs?*, 152 SCI. NEWS 31, 31 (1997).

93. Ohio's largest single bat colony lives in an abandoned mine. *See* Bruce A. Stein & Stephanie R. Flack, *Conservation Priorities: The State of U.S. Plants and Animals*, ENVIRONMENT, May 1997, at 6, 37. Further, I know from personal observation that millions of bats live under a bridge in Austin, Texas. Species sometimes thrive in ongoing human disturbance regimes. For example, in an effort to reduce common leaf rust, Latin American coffee plantation owners began switching in the 1970s from shade to full sun growing techniques. *See* T. Adler, *Coffee Can Give Many Species a Boost*, 150 SCI. NEWS 132, 132 (1996). Biologists now are finding that the thick underbrush and dense canopies of shade plantations provided species-rich islands of habitat in otherwise deforested areas, whereas the new sun method plantations are virtually devoid of birds and small mammals. *See id.* In other words, even though one type of human disturbance adversely affected the environment, species thrived amidst another type of disturbance. Similarly, studies of the Colorado River below the Glen Canyon Dam show that the damming and flow control promoted populations of trout in the cold water below the dam and allowed trees and shrubs to establish along the shoreline, providing habitat to several endangered birds. *See* Collier et al., *supra* note 82, at 82, 83. The decision to adjust the flow to more closely approximate the pre-dam conditions necessarily sacrificed those ecosystem states for another set. *See id.* at 83 (observing that although the dam brought about some beneficial changes, it also dramatically altered the area's vegetation).

94. For example, efforts to restore duck and goose habitats in the United States have resulted in a snow goose population explosion that threatens the snow

These sources of uncertainty make societal decisions all the more difficult, as we are unsure what effects our behavior will have on the environment.[95] A growing effort to explain these properties through complexity theory and the depiction of ecosystems as complex adaptive systems promises to improve our understanding of their origins and inevitability.[96]

2. Technology. Although it may seem that the cart led to the carriage, which led to the prototype automobile, which led to the station wagon, which led to today's sport utility vehicle, technological advancement is much more of a nonlinear process.[97] As James Burke concludes in his epic study of the technological developments that have shaped modern society,[98] technology is often portrayed in reductionist terms as progressing through discrete time and theme phases and through the efforts of individual "inventors," but this is seldom the case.[99] In reality,

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goose habitat as well as the habitat of other species, some already endangered, that nest in the same arctic region. *See* United States Fish and Wildlife Service, United States Department of Interior, News Release, *Report Warns that Snow Goose Population Explosion Threatens Arctic Ecosystems* (April 1, 1997) <www.fws.gov>.

95. Indeed, "[t]he degree of uncertainty is high at small scales . . . and is magnified as scale approaches the landscape level." David N. Wear et al., *Ecosystem Management With Multiple Owners: Landscape Dynamics in a Southern Appalachian Watershed,* 6 ECOLOGICAL APPLICATIONS 1173, 1174 (1996).

96. *See, e.g.,* Brown, *supra* note 1, at 420; R.F. Costantino et al., *Chaotic Dynamics in an Insect Population,* 275 SCIENCE 389, 389-91 (1997) (discussing chaotic behavior of flour beetles); Robert Costanza et al., *Modeling Complex Ecological Economic Systems,* 43 BIOSCIENCE 545, 545 (1993) (noting new ways for modeling interactions between anthropogenic and natural systems); Alan Hastings & Kevin Higgins, *Persistence of Transients in Spatially Structured Ecological Models,* 263 SCIENCE 1133, 1133 (1994) (opining that because there are typically sudden changes in the form of a species's dynamics over the thousands of years it may take a species to reach its final dynamics, complex transient dynamics in ecological models may be more relevant than long-term behavior); Simon A. Levin et al., *Mathematical and Computational Challenges in Population Biology and Ecosystems Science,* 275 SCIENCE 334, 334 (1997) (stating that "[m]athematical and computational approaches to biological questions . . . are now recognized as providing some of the most powerful tools in learning about nature"); Douglas S. Robertson & Michael C. Grant, *Feedback and Chaos in Darwinian Evolution,* COMPLEXITY, Nov.-Dec. 1996, at 18 (applying chaos theory to develop a numerical model depicting Darwinian natural selection); Karl Sigmund, *Darwin's "Circles of Complexity": Assembling Ecological Communities,* COMPLEXITY, Jan. 1995, at 40 (applying complexity theories to analyze the stability of ecosystems).

97. For a more extensive discussion of this property of technology change and its analogical values for the legal system, see Ruhl & Ruhl, *Arrow of Law, supra* note 15, at 444-52.

98. *See generally* JAMES BURKE, CONNECTIONS (1978). Burke's wonderfully written book carries the reader through the decidedly nonlinear development and cultural impacts of a rich variety of technologies, including clocks, looms, buttons, money, and the zoopraxiscope.

99. *See id.* at 288 (observing that the characterization of an individual as sole

the triggering factor in technological advancement "is more often than not operating in an area entirely unconnected with the situation which is about to undergo change."[100] Thus, a linear view of technological change misses many of the major points and distorts what it does reveal.[101] Despite the prevailing linear conception, the reality is that throughout history, and no doubt for the future as well, the major events of technological advancement are the result of "a fascinating mixture of accident, climactic change, genius, craftsmanship, careful observation, ambition, greed, war, religious belief, deceit, and a hundred other factors."[102]

The reductionist, linear view of technological advancement influences society profoundly, in what Edward Tenner calls the "perils of technological extrapolation."[103] We tend to overlook the nonlinear reality of technological advancement that defies extrapolation of perceived trends, and we make mistakes as a result.[104] Society's response to problems associated with technology is usually to employ yet more technology, because that is what society knows best how to do, and that is what was done before.[105] In other words, technological advancement breeds yet

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creator exaggerates his influence and denies the involvement of others whose work was necessary to the invention). Burke's detailed history of events shaping technological change shows that the periodic, thematic, and heroic treatments tend to ignore the overlapping nature of so-called periods, imply a degree of foreknowledge where none exists, and exaggerate the influence of individuals over events.

100. *Id.* at 289. *See also* James Burke, *The Silk Road*, SCI. AM., Nov. 1995, at 109, 109 (declaring that "[r]eductionism simply does not begin to describe this complex, serendipitous process [of technology innovation], in which even apparently trivial elements have the most important effects").

101. For example, Burke points out that

> [a] linear view of the past would, for instance, place the arrival of the chimney in a sequence of developments relating to change in domestic living. Yet the alteration of life-style brought about by the chimney included year-round administration and increased intellectual activity, which in turn contributed to a general increase in the economic welfare of the community to a point where the increase in the construction of houses brought about a shortage of wood. The consequent need for alternative sources of energy spurred the development of a furnace which would operate efficiently on coal, and this led to the production of molten iron in large quantities, permitting the casting of the cylinders which were used in the early steam engines.

BURKE, *supra* note 98, at 289.

102. *Id.* at 13; *see also* Michael Shermer, *The Crooked Timber of History*, COMPLEXITY, July-Aug. 1997, at 23, 24-26 (discussing complexity theory applications to the study of history).

103. EDWARD TENNER, WHY THINGS BITE BACK at x (1996).

104. *See id.* at 254-77 (giving examples of how technological advancements and improvements have lead to discontent).

105. As Burke puts it:

> [M]ost of us take the only available course: we ignore the vulnerability of our position, since we have no choice but to do so. We seek security in the rou-

more technological advancement, in what Tenner calls the "intensiveness effect," through which problems such as environmental degradation are addressed by intensifying the technological apparatus.[106] This reality of technological change has deep implications for environmental policy:

> *1. Many technological innovations affecting the environment for good or bad are the result of serendipity rather than concerted effort.*[107]
>
> *2. Many efforts to bring about technologic change on behalf of the environment fail to do so as expected or within the time frame that was considered feasible.*[108]
>
> *3. The full environmental effects of technological change are difficult to measure and may take many years to fully manifest themselves.*[109]

> tines imposed by the technological systems which structure our lives into periods of work and rest. In spite of the fact that any breakdown in our interdependent world will spread like ripples in a pool, we do not believe that the breakdown will occur. Even when it does, . . . our first reaction is to presume that the fault will be rectified, and that technology will, as it always has, come to the rescue.

BURKE, *supra* note 98, at 6.

106. *See* TENNER, *supra* note 103, at 270-77.

107. For example, the discovery of "extremophile" organisms living near deep ocean vents and surviving on a toxic brew of chemicals released from the vents may lead to innovative waste remediation biotechnologies. *See* Richard Monastersky, *Deep Dwellers: Microbes Thrive Far Below Ground*, 151 SCI. NEWS 192, 193 (1997) (stating that subsurface microbes can provide industry with a method for cleaning wastewater because they can consume toxic chemicals and thrive in industrial wastewater).

108. For example, the development of "zero-emission vehicles" is moving slowly, and some concerns have been raised that initial electric car prototypes could pose a net negative effect for the environment in certain countries. *See* Camilla Kazimi, *Evaluating the Environmental Impact of Alternative-Fuel Vehicles*, 33 J. ENVTL. ECON. & MGMT. 163, 164-65 (1997) (positing that use of limited range electrical vehicles in multi-car families could lead to greater emissions); Eliot Marshall, *Slower Road for Clean-Car Program*, 276 SCIENCE 194, 194 (1997); *Technologies for Next-Generation Car Should Not be Pared Too Soon, Report Says*, 27 Env't Rep. (BNA) 2490, 2490 (1997). *But see* Daniel Sperling, *The Case for Electric Vehicles*, SCI. AM., Nov. 1996, at 54 (discussing advantages of electric vehicles).

109. For example, the persistence of acid rain after a decade of technological improvements that succeeded in substantially reducing industrial sulfur dioxide emissions has led researchers to conclude that other phenomena, such as reductions in atmospheric dust brought about by improved farming techniques, contribute to acid rain in previously unanticipated ways. Oddly, the efforts to reduce air emissions from one set of sources have offset the efforts to reduce different emissions from other sources. *See* Lars O. Hedin & Gene E. Likens, *Atmospheric Dust and Acid Rain*, SCI. AM., Dec. 1996, at 85, 86 (noting that the bases in the dust neutralize the acids in industrial emissions, but as dust emissions are reduced, that effect also was reduced).

4. In highly technological societies, small failures in technology can spread rapidly and virulently through the technological infrastructure.[110]

Complexity theory researchers such as Stuart Kauffman have begun to describe these properties of technological change using the core concepts of complexity theory, given their close fit with the properties of complex adaptive systems.[111] For example, Kauffman points to the presence of fitness jumps followed by decreasing returns that can be found in the historical record of new technologies.[112] The implications of this emerging view of technology as a complex adaptive system lead inevitably to consideration of how environmental law and policy respond to technological change and failure.

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110. A frightening example, though not related to environmental policy, is the so-called Year 2000 computer problem, in which computer software used to run many mainframes and PCs reads years ending in 00 as the year 1900. *See* IVARS PETERSON, FATAL DEFECT 114-15 (1995) (discussing the Year 2000 problem). The problems caused by that rather trivial programming defect will require massive expenditures to correct before the year 2000. *See id.* at 118 (stating that averting the possible Year 2000 disaster will require considerable effort). Estimates are that it will cost New York City over $100 million to fix this "glitch" and the United States government $2.3 billion to $5.6 billion. *See* James Kim, *One-Man Army Fights His City's Year 2000 Hitch*, USA TODAY, Apr. 29, 1997, at B1. Even small towns face expenditures over $100,000. *See id.* (stating that North Platte, a small Nebraska town with a population of 24,500, will have to pay $150,000 to hire programmers to handle the Year 2000 problem). Naturally, lawyers have noticed the problem and its potential litigation consequences. *See* Jon Newberry, *Beat the Clock*, A.B.A. J., June 1997, at 49, 50 (predicting numerous lawsuits brought by and against victims of the "millennium bug").

111. Kauffman, whose work adapting complexity theory to evolutionary biology has been highly influential, posits:

> Both organisms and artifacts confront conflicting design constraints. As shown, it is those constraints that create rugged fitness landscapes. Evolution explores its landscapes without the benefit of intention. We explore the landscapes of technological opportunity with intention, under the selective pressure of market forces. But if the underlying design problems result in similar rugged landscapes of conflicting constraints, it would not be astonishing if the same laws governed both biological and technological evolution.

KAUFFMAN, AT HOME IN THE UNIVERSE, *supra* note 8, at 192. *See also* Larry J. Eriksson, *How Technology Evolves*, COMPLEXITY, Jan.-Feb. 1997, at 23, 23 (describing how technological innovation results from the development of a new technology combined with new performance requirements for old technology).

112. Kauffman explains that

> [d]uring the initial phase of rapid improvements, investment in the new technology yields rapid improvement in performance. This can yield what economists call increasing returns, which attract investment and drive further innovation. Later, when learning slows, little improvement occurs per investment dollar, and the mature technology is in a period of what economists call diminishing returns. Attracting capital for further innovation becomes more difficult. Growth of that technology sector slows, markets saturate, and further growth awaits a burst of fundamental innovation in some other sector.

KAUFFMAN, AT HOME IN THE UNIVERSE, *supra* note 8, at 203.

3. Economies. Is there any rational explanation for why thousands of parents combed through toy stores in 1996 looking for "Tickle Me Elmo" dolls for which they were willing to pay exorbitant premiums?[113] Why were the parents, the toy stores, and the doll manufacturer unable to predict the demand for that doll? The answer to the first question is no. The answer to the second question is that no one can accurately predict consumer demand in all cases. Consumers and firms, once you amass enough of them, often act collectively in seemingly irrational, unpredictable, evolving ways—in other words, as a complex adaptive system. This quality has not gone unnoticed in complexity theory research, as one of the first branchings of the field into the social sciences involved economic theory and the study of consumer and market behavior.[114]

Consumption presents a thorny problem for environmental policy. Even before the environmental revolution of the 1970s, environmentalists such as Paul Ehrlich argued that the total burden humans place on the environment is a function of three variables: population, affluence, and technology.[115] We have seen the importance of technology to environmental policy;[116] population and affluence combine to account for the consumption factor.[117] Indeed, one of the raging debates of environmental policy is where to focus the effort: on population control, consumption restraints, or technological innovation.[118] Where technological

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113. *See The Holiday Trends That Stole Christmas*, NY TIMES, Dec. 22, 1996, at A43 (describing Tickle Me Elmo dolls as "sending parents into near-hysterics trying to find one").

114. *See, e.g.*, W. BRIAN ARTHUR, INCREASING RETURNS AND PATH DEPENDENCE IN THE ECONOMY (1994); PAUL KRUGMAN, THE SELF-ORGANIZING ECONOMY 2 (1996) (applying common principles of complexity to economic analysis); Costanza et al., *supra* note 96, at 545 (observing that both ecological and economic systems exhibit characteristics of complex systems).

115. *See* PAUL R. EHRLICH, THE POPULATION BOMB 1-44 (1968). Ehrlich's "equation" is largely a modern variation on Malthus's theory of population growth outstripping food supply growth. *See* THOMAS R. MALTHUS, AN ESSAY ON THE PRINCIPLE OF POPULATION 11-38 (MacMillan & Co. Ltd. 1966) (1798) (predicting checks on population growth due to inability of food and nutrition to support such growth); *see also* Stuart L. Hart, *Beyond Greening: Strategies for a Sustainable World*, HARV. BUS. REV., Jan.-Feb. 1997, at 66, 70 (providing a recent look at the Ehrlich formula).

116. Refer to Part II.B.2 *supra* and accompanying text.

117. *See* Hart, *supra* note 115, at 70.

118. *See id.* at 70-71. Two "camps" have formed around this question, with diametrically opposed answers. Ehrlich leads the camp contending that consumption must be drastically controlled. *See* EHRLICH, *supra* note 115, at 48-49 (predicting that as the food crisis intensifies the rate of soil deterioration will increase). The economist Julian Simon leads the camp contending that technological change will prevent rising consumption from depleting and destroying natural resources. *See* Julian L. Simon, *Resources, Population, Environment: An Oversupply of False Bad News*, 208 SCIENCE 1431, 1436 (1980) (stating that the key constraint upon the lim-

change causes environmental problems or is unresponsive to existing problems, consumption is a necessary focus of environmental policy.[119] But just as technological change exhibits complex adaptive system behavior that befuddles environmental policy, so too will consumption:

1. Controlling growth in global consumption will be difficult as developing countries understandably aspire to higher standards of living for their large populations.[120]

2. Deeply embedded consumption patterns are difficult to change even when the environmental goals are well understood and widely accepted.[121]

3. Because the environmental effects of consumption are often far removed from the locus of consumption, consumers

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its of natural resources is the limit upon knowledge and technological innovation). Additionally, a hybrid view appears to be emerging in which rational policy responses are called for with respect to both consumption and technology. *See* Jesse H. Ausubel, *Can Technology Spare the Earth?*, 84 AM. SCIENTIST 166, 177 (1996) (arguing that technology enables people to obtain goods and services more efficiently and that technology used wisely "can spare the earth").

119. *See* Jonathan Harris, *Consumption and the Environment: Overview Essay*, *in* THE CONSUMER SOCIETY 269-76 (Neva Goodwin et al. eds., 1997) (reviewing the issues surrounding consumption and its effects on the environment); Norman Myers, *Consumption in Relation to Population, Environment and Development*, 17 ENVIRONMENTALIST 33, 34-37 (1997); Arnold W. Reitze Jr., *Population, Consumption, and Environmental Law*, 12 NAT. RESOURCES & ENV'T __ (forthcoming) (draft on file with the *Houston Law Review*).

120. China, for example, has over one billion people, only one million cars, and one of the world's fastest growing economies. *See* Hart, *supra* note 115, at 75. Even a heavy dose of population and affluence controls designed to suppress China's consumption of cars will not avoid the reality that tens of millions of hydrocarbon-burning cars are going to be headed to China in the next decade, which suggests that a concerted international effort to develop pollution control technology for cars is warranted. *See id.* Although most fingers point at the United States for its high rate of consumption per capita, the inevitable marginal increases in consumption by huge numbers of poor people present a far more intractable problem for the future of environmental policy. *See* Myers, *supra* note 119, at 34; *see also* Vaclav Smil, *China Shoulders the Cost of Environmental Change*, ENVIRONMENT, July-Aug. 1997, at 6, 7-9, 33-36 (documenting the environmental costs of China's rapidly expanding economy).

121. Consider, for example, the effort under the Clean Air Act to require employers in certain cities to enforce car pooling among their employees. *See* 42 U.S.C. § 7408(f)(1)(A) (1994) (addressing pollution control measures); *see also id.* § 7511a (c)(5)(A) (discussing transportation control measures). The persons responsible for that idea obviously had never lived and worked in Houston, where land use and employment patterns make the "consumption" of driving alone practically mandatory. *See* Caleb Solomon, *Head-On Collision: Cut Auto Commuting? Firms and Employees Gag at Clean-Air Plan*, WALL ST. J., Sept. 8, 1994, at A1 (stating that Houston residents will continue to drive because of the lack of a mass transit system and the fact that subtropical weather and long commutes make walking and biking impracticable).

often fail to make connections between their behavior and its environmental consequences.[122]

The list can go on. The sad reality is that "[i]n their roles as consumers and producers, members of the social classes most favoring increased environmental protection have lifestyles intimately associated with massive waste-generating activities including, for example, the serious environmental problems associated with solid waste, automobiles, and the advances in technology."[123] For this reason, solving the consumption problem will be like herding cats.

4. Land Use. Land use, in particular the conversion of land from undisturbed natural states to agricultural and urban uses, has a profound impact not only on the land under development, but also on the surrounding ecosystems.[124] Unfortunately, we have absolutely no idea how to design land use policies around this ecological reality.[125] Even if we could get a handle on ecosystem dynamics, two decades of experience under legal frameworks for active growth management leave us with much remaining to be understood about the dynamics of land use and

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122. For instance, despite nonstop bombardment with save-the-rainforest rhetoric, consumers are willing to pay premiums for tropical hardwood products. *See* Richard E. Rice et al., *Can Sustainable Management Save Tropical Forests?*, SCI. AM., Apr. 1997, at 44, 47 (noting that while valuable species such as Mahogany are up to five times more profitable than a more sustainable alternative, consumers are only willing to pay 10% more for the alternative). Additionally, the live reef food fish trade, valued at more than $1 billion a year in Hong Kong and China, has tremendously adverse effects on the far away reefs from where the fish are taken by anesthetizing squirts of cyanide. *See* Rita Ariyoshi, *Halting a Coral Catastrophe*, NATURE CONSERVANCY, Jan.-Feb. 1977, at 20. Likewise, fishing for groundfish off the New England coast with deep seabed "rock hopper" gear destroys the structurally complex rock bottom of the seabed that provides the best shelter for the next generation of groundfish. *See* Janet Raloff, *Fishing for Answers: Deep trawls leave destruction in their wake—but for how long?*, 150 SCI. NEWS. 268, 268 (1996). The distance effect is caused in part by geographical separation. For example, the service industries generate enormous indirect environmental effects felt at distant points in the economy, such as by virtue of their product selection decisions. *See* Brad Allenby, *Clueless*, ENVTL. F., Sept.-Oct. 1997, at 35, 35-37; David Rejeski, *An Incomplete Picture*, ENVTL. F., Sept.-Oct. 1997, at 26, 26-34.

123. PETER CLEARY YEAGER, THE LIMITS OF LAW 307 (1991). *See also* Arnold W. Reitze, Jr., *Federalism and the Inspection and Maintenance Program Under the Clean Air Act*, 27 PAC. L.J. 1461, 1474 (1996) (observing that "Americans are not eager to sacrifice to protect the environment. They want both a clean, safe environment and the freedom to behave in a manner that makes protecting such an environment very difficult").

124. *See* Peter Vitousek et al., *Human Domination of Earth's Ecosystems*, 277 SCI. 494, 494 (1997) (explaining how "[t]he use of land to yield goods and services represents the most substantial human alteration of the Earth system").

125. *See id.* at 495 (stating that "[u]nderstanding land transformation is a difficult challenge; it requires integrating the social, economic, and cultural causes of land transformation with evaluations of its biophysical nature and consequences").

land markets at the so-called urban fringe, their effects on ecosystems, and which policy approaches work.[126] Difficulties faced when attempting to manage land use with ecological goals include the following:

1. Neither land use nor ecological biodiversity are uniform in appearance or concentration, leading to potential collisions of large scales.[127]

126. As one commentator has observed, "[m]anaging growth so as to mitigate its impacts on natural resource systems is a major challenge due to the complex behavior of these systems, the diverse intergovernmental programs for environmental protection, and the fragmented state of knowledge about linkages between growth and natural resources." John S. Banta, *Environmental Protection and Growth Management*, *in* UNDERSTANDING GROWTH MANAGEMENT 134, 134 (David J. Brower et al. eds., 1989). *See also* Elizabeth Deakin, *Growth Controls and Growth Management: A Summary and Review of Empirical Research*, *in* UNDERSTANDING GROWTH MANAGEMENT 12 (David J. Brower et al. eds., 1989) (stating that "broader questions of effectiveness, such as whether the programs are working as intended, are scoped appropriately, and have reasonable benefit-cost ratios, remain largely unaddressed"); James H. Brown et al., *Land Markets at the Urban Fringe: New Insights for Policy Makers*, 47 J. AM. PLAN. ASS'N 131, 131 (1981) (observing that "relatively little is known about who owns rural land at the periphery of growing metropolitan areas and how these landowners behave"); John D. Landis, *Do Growth Controls Work?: A New Assessment*, 58 J. AM. PLAN. ASS'N 489, 503 (1992) (noting that "[m]any questions about the efficacy of local growth controls still remain to be answered").

127. One study estimates that over 90% of the species listed under the Endangered Species Act as endangered or threatened have some or all of their habitat on nonfederal lands. *See* U.S. GEN. ACCOUNTING OFFICE PUB. NO. GAO/RCED-95-16, SPECIES PROTECTION ON NONFEDERAL LANDS 4 (1994). Of those species on the list, 73% have over 60% of their habitat on nonfederal lands, and 37% are completely dependent on nonfederal lands. *See id.* at 5. Another study demonstrates that a mere 7% of the land area of the United States is home to fully 50% of plant and animal species listed under the Endangered Species Act, and that the "hot spots," within which many different at-risk species appear in clusters, are often located near areas experiencing suburban expansion. *See* T. Adler, *Mapping Out Endangered Species' Hot Spots*, 150 SCI. NEWS 101, 101 (1996) (describing how 50% of the listed endangered species in the United States exist on only 7% of the land area presents problems for managing that small amount of land); A.P. Dobson et al., *Geographic Distribution of Endangered Species in the United States*, 275 SCIENCE 550, 551 (1997) (explaining how the amount of land that needs to be managed to protect currently endangered and threatened species in the United States is a relatively small proportion of the land mass); Jon Paul Rodriguez et al., *Where are Endangered Species Found in the United States?*, ENDANGERED SPECIES UPDATE, Mar.-Apr. 1997, at 1, 3-4 (explaining how more than 90% of the listed endangered species in the United States are found in Hawaii, California, Florida, Texas, and southwestern Appalachia and more than 95% of those are on private lands). Hence, although the built-up land area is not a large proportion of the total national land area, it so happens that further expansion of the built-up area poses a serious threat to many endangered species and sensitive ecosystems. *See* William Stolzenberg, *Habitat Is Where It's At*, NATURE CONSERVANCY, Nov.-Dec. 1997, at 6, 6 (discussing a recent study that identifies, based on federal agency records, habitat loss as the most frequently cited reason for endangerment of species).

2. Many of the most difficult problems in environmental policy are associated with complex agricultural and urban land use patterns.[128]

3. The impact of urban and suburban development increasingly can be felt far outside the development fringe as inhabitants import resources from outlying areas and export pollution in return.[129]

4. Most ecologists are now convinced that preserving ecosystem integrity—that is, the mix of biota and physical traits that underlie the complex adaptive system qualities of ecosystems—requires preserving many large, contiguous, undisturbed tracts of land.[130]

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128. For example, federal regulation of air and water pollution in the 1970s and the 1980s focused on so-called "end-of-the-pipe" controls on stationary, discrete "point sources," largely because such sources were easier to control, both politically and administratively. Today, however, nonpoint source water pollution, which includes diffuse runoff from streets, farms, mines, and other areas, accounts for a substantial amount of the contamination in polluted rivers and impaired lakes. *See* ENVIRONMENTAL PROTECTION AGENCY, NATIONAL WATER QUALITY INVENTORY: 1994 REPORT TO CONGRESS 403 (1995) (providing background on the problem of nonpoint source pollution). Controlling the diffuse and numerous sources of nonpoint source water pollution has proven difficult at both the federal and state levels. *See* David Zaring, *Federal Legislative Solutions to Agricultural Nonpoint Source Pollution*, 26 Envtl. L. Rep. (Envtl. L. Inst.) 10128, 10128-32 (1996) (relating that nonpoint sources are responsible for 65 to 75% of the nation's pollution and that nonpoint sources are the predominant causes of pollution in 42 states).

129. *See* P. A. Matson et al., *Agricultural Intensification and Ecosystem Properties*, 277 SCIENCE 504, 507 (1997) (noting that "[a]lthough agroecosystems are typically managed in isolation from other ecosystems within a region, the physical, ecological, and biogeochemical changes that take place within them have numerous consequences for adjacent, and even distant, ecosystems"); Vitousek et al.., *supra* note 124, at 495 (explaining how "the effects of land transformation extend far beyond the boundaries of transformed lands"). For example, the vast majority of Nevada's 1.4 million residents live in two metropolitan areas covering less than 1% of the state's land area. An additional 3% of the state is devoted to agricultural uses. That 4% of total land cover, however, draws massive amounts of water from the Colorado River, thus making its presence felt at considerable distances. *See* Paul R. Ehrlich & Anne H. Ehrlich, *Biodiversity and the Brownlash*, DEFENDERS, Fall 1996, at 6, 8. For a comprehensive discussion of the direct and indirect effects of human populations on the environment, many of which are felt far beyond the built up boundary of human occupation, see ANDREW GOUDIE, THE HUMAN IMPACT ON THE NATURAL ENVIRONMENT 1-28 (4th ed. 1993) (reviewing the history and evolution of mankind and its effect on the environment).

130. A focal point of conservation biology research has been to demonstrate the often pernicious effects of habitat fragmentation. It appears to be indisputable, for example, that a circular preserve of 1000 contiguous acres offers more ecological value to many species than would 10 unconnected preserves of 100 acres each. Smaller preserve structures increase the total linear "edge" of preserve boundaries, which can present opportunities to predators, and many species have been demonstrated to depend on a minimum "patch size" of habitat in order to carry out essential breeding, feeding, and sheltering functions. *See* Denis A. Saunders et al., *Biological Consequences of Ecosystem Fragmentation: A Review*, CONSERVATION BIOLOGY, Mar. 1991, at 18, 24-25 (noting that the larger the "remnant," the more

In other words, while land use policies must take into account ecosystem dynamics, development in the urban-suburban-exurban-rural phase transition zones is unpredictable and slippery, like a complex adaptive system. Thus, it does not lend itself well to policies based on reductionist generalizations and linear extrapolations.[131]

III. ENVIRONMENTAL LAW ACTS AS IF ITS SUBJECT MATTER IS REDUCIBLE, LINEAR, AND PREDICTABLE

Although all fields of law regulate human behavior, environmental law is different. Environmental law regulates human behavior toward the environment. This quality presents a two-fold challenge for environmental law, for both the target of environmental

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likely it is that populations will be large, and, consequently, there will tend to be higher levels of heterozygosity). The edge effect is not all bad in all cases, however, as the increased interplay of species in that zone may lead to increased speciation as a force of adaptation. *See* Martin Enserink, *Life on the Edge: Rainforest Margins May Spawn Species*, 276 SCIENCE 1791, 1791 (1997) (observing that many new species arise not in the rainforests but on its edges). Knowing whether the impact of human land use on ecosystems will be good or bad, by whatever measure we choose for that normative inquiry, is difficult because the effects of fragmentation and other land use impacts often exhibit themselves not incrementally, but with a nonlinear "critical threshold" effect which appears without warning and thereafter produces dramatic ecological responses. *See* Kimberly A. With & Thomas O. Crist, *Critical Thresholds In Species' Responses to Landscape Structure*, 76 ECOLOGY 2446, 2446 (1995). Similar challenges are faced in the context of designing marine preserve areas. *See* Karen F. Schmidt, *'No-Take' Zones Spark Fisheries Debate*, 277 SCIENCE 489, 490-91 (1997) (discussing the issues with regard to size, design, and layout of marine reserves). While they may be difficult to measure in specific species contexts, it seems widely agreed in the scientific community that these factors exist in general and pose significant challenges for preserve design and management for many species.

131. The land development process, particularly the decisions of land developers, is largely ad hoc, unsystematic, and often based on developers' experience and "gut feel." *See* George A. McBride & Marion Clawson, *Negotiation and Land Conversion*, 36 J. AM. INST. PLANNERS 22, 25 (1970). As a result, however, the land development process becomes highly adaptable to whatever is thrown in its path. A classic example comes from Vermont, where a state law designed to mitigate the adverse community and environmental impacts of large-scale developments simply led to a proliferation of small-scale projects designed to avoid the effects of the law. *See* Thomas L. Daniels & Mark B. Lapping, *Has Vermont's Land Use Control Program Failed?*, 50 J. AM. PLAN. ASS'N 502, 507 (1984). Growth control programs in general have thus been criticized as being too narrow in problem specification, overly optimistic in expected compliance, and inattentive to the potential for unintended responses and results. *See* Deakin, *supra* note 126, at 13-14 (criticizing planners for narrowly focusing on the increased traffic resulting from population growth and ignoring the increases attributable to existing residents); Lee R. Epstein, *Where Yards Are Wide: Have Land Use Planning and Law Gone Astray?*, 21 WM. & MARY ENVTL. L. & POL'Y REV. 345, 356-66 (1997) (criticizing the "scientific" basis of land planning law for contributing to "sprawl"—large expanses of low-density, single-use development at the edges of urban development).

regulation, humans, and the purported beneficiary of regulation, the environment, display the discontinuities and synergies characteristic of complex adaptive systems. Thus, it is not surprising to find few issues of environmental policy that can be described as easy, uncomplicated, or well-defined. Rather, environmental policy issues usually are multidimensional and multidisciplinary; they involve monetary and nonmonetary aspects; they involve scarce resources upon which the effects of policy decisions may be irreversible; their impacts are multisectorial and felt over broad scales of time and space; and they carry with them high levels of uncertainty of causation and outcome.

By and large, unfortunately, modern American environmental law is not designed based on that fundamental reality. Rather, both the present structure of the law as well as the most touted proposed reforms display an amazing degree of ignorance of complex adaptive system dynamics. The underlying tradition of environmental law—a tradition that is hardly abandoned in current reform frameworks—is based on a conception of nature as uniformitarian, a nature in which change takes place, but in the form of trends that are capable of extrapolation and prediction which lead toward an ordered state of equilibrium. We know that this paradigm is a fiction; so why does our legal framework cling to it?

A. *The Fallacious Uniformitarian Premises of Environmental Law—Examples from the Endangered Species Act*

The structure of environmental law provides a striking illustration of how society has attempted, through the law, to tame the complex adaptive systems that make up our world. We do so, however, not with complex adaptive system structure in mind, but rather with the mind set of classical science. A fitting example is found in the Endangered Species Act ("ESA"),[132] which, in explicit recognition of ecosystem-level dynamics, purports to "provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved,"[133] but does so in a manner that can only be called reductionist, linearist, and predictivist.[134] Indeed, ecosystems appear

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132. 16 U.S.C. §§ 1531-1544 (1994).

133. *Id.* § 1531(b).

134. The statute has been roundly criticized for not following through with coherent ecosystem management measures. *See* Holly Doremus, *Patching the Ark: Improving Legal Protection of Biological Diversity*, 18 ECOLOGY L.Q. 265, 304-17 (1991) (faulting the ESA for failing to protect biological and species diversity); James Drozdowski, *Saving an Endangered Act: The Case for a Biodiversity Approach to ESA Conservation Efforts*, 45 CASE W. RES. L. REV. 553, 582-85 (1995) (criticizing

to have been the last thing on Congress's mind when it drafted the ESA.[135]

1. Reductionism. The core provisions of the ESA require the Secretaries of the Departments of the Interior and Commerce to "list" species that are determined to be endangered or threatened with extinction.[136] Further, the "critical habitat" of each such species is to be designated,[137] and a species "recovery plan" must be prepared.[138] Federal agencies must avoid "jeopardizing" the

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the ESA for narrowly focusing on the protection of specific "endangered" or "threatened" species and ignoring the ecosystem as a whole); Andrew A. Smith et al., *The Endangered Species Act at Twenty: An Analytical Survey of Federal Endangered Species Protection,* 33 NAT. RESOURCES J. 1027, 1069-72 (1993) (characterizing the ESA as a "reactive" statute that does little to prevent species from becoming endangered and arguing that a "proactive" ecosystem protection approach would be more effective).

135. The discussion that follows in the text is not intended to provide a comprehensive overview of the ESA, but rather to focus on its basic structural orientation. For comprehensive discussions of the core ESA programs, see generally RICHARD LITTELL, ENDANGERED AND OTHER PROTECTED SPECIES (1992); Oliver A. Houck, *The Endangered Species Act and Its Implementation by the U.S. Departments of Interior and Commerce,* 64 U. COLO. L. REV. 277, 279 (1993) (claiming that despite its seemingly rigid blueprint, the ESA has been implemented in a discretionary manner); James C. Kilbourne, *The Endangered Species Act Under a Microscope: A Closeup Look From a Litigator's Perspective,* 21 ENVTL. L. 499, 501 (1991) (focusing on the ESA's "key provisions" from a litigator's view). Some, but clearly not all, of the deficiencies identified here are addressed in proposed ESA reform legislation. *See* S. 1180, 105th Cong. (1997).

136. Section 4(a)(1) of the ESA requires the Secretaries to designate any species of plant or animal the continued existence of which is "endangered" or "threatened." *See* 16 U.S.C. § 1533(a)(1). For an overview of the definitions and procedures used for listing species, see LITTELL, *supra* note 135, at 15-25; Houck, *supra* note 135, at 280-96; J.B. Ruhl, *Section 4 of the ESA—The Cornerstone of Species Protection Law,* NAT. RESOURCES & ENV'T, Summer 1993, at 26, 26-29, 67-68.

137. Section 4(a)(3) of the ESA requires the Secretaries to designate the "critical habitat" of listed species "to the maximum extent prudent and determinable." 16 U.S.C. § 1533(a)(3). For an overview of the critical habitat designation process, see LITTELL, *supra* note 135, at 26-27; Houck, *supra* note 135, at 296-315 (claiming that the concept of protecting critical habitat "has turned out to be an agony of the ESA"); James Salzman, *Evolution and Application of Critical Habitat Under the Endangered Species Act,* 14 HARV. ENVTL. L. REV. 311, 331-38 (1990) (examining the "critical habitat" provision as the strongest enforcement provision of the ESA); Katherine Simmons Yagerman, *Protecting Critical Habitat Under the Federal Endangered Species Act,* 20 ENVTL. L. 811, 834-45 (1990) (maintaining that the ESA has not furthered its mandate for habitat protection).

138. Section 4(f) of the ESA requires the Secretaries to "develop and implement plans . . . for the conservation and survival of endangered species and threatened species." 16 U.S.C. § 1533(f). For an overview of the history and potential of the recovery planning process under § 4(f) of the ESA, see LITTELL, *supra* note 135, at 28-30; Federico Cheever, *The Road to Recovery: A New Way of Thinking About the Endangered Species Act,* 23 ECOLOGY L.Q. 1, 34-42 (1996) (providing a history of the recovery program); Houck, *supra* note 135, at 344-51 (arguing that the scope and definition of "recovery" in the ESA provides a broad mandate yet has been plagued

continued existence of such species,[139] and all persons must ensure that they do not "take" endangered animal species.[140] What happened to ecosystems?

Indeed, the Fish and Wildlife Service ("FWS"), which implements the ESA for the Department of Interior, and the National Marine Fisheries Service ("NMFS"), which is part of the Department of Commerce, recently declined to adopt a policy of basing species population listing decisions on the importance of a population to the ecosystem in which it occurs.[141] The agencies explained that "[d]espite its orientation toward conservation of ecosystems, the Services do not believe the Act provides authority to recognize a potential [population] as significant on the basis of the importance of its role in the ecosystem in which it occurs."[142] Similarly, they rejected a proposal that stresses uniqueness and irreplaceability of ecological functions in such

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by a history of doubtful effectiveness).

139. Section 7(a)(2) of the ESA initiates a complicated set of provisions flowing from the duty of federal agencies to consult with the Fish and Wildlife Service ("FWS") and the National Marine Fisheries Service ("NMFS") to "insure that any action authorized, funded, or carried out by such agency . . . is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat of such species which is determined . . . to be critical." 16 U.S.C. § 1536(a)(2). For an overview of the interagency consultation procedure under § 7 of the ESA, see LITTELL, *supra* note 135, at 52-54; Houck, *supra* note 135, at 315-29; Kilbourne, *supra* note 135, at 530-64 (explaining the requirements and procedures of the conference process).

140. The most powerful regulatory consequence to flow from species listing, and perhaps the most powerful regulatory provision in all of environmental law, is found in § 9(a) which makes it unlawful for "any person subject to the jurisdiction of the United States to . . . take any such species within the United States or the territorial sea of the United States." 16 U.S.C. § 1538(a)(1)(B). For an overview of the "take" prohibition as implemented, see LITTELL, *supra* note 135, at 70-73; Federico Cheever, *An Introduction to the Prohibition Against Takings in Section 9 of the Endangered Species Act of 1973: Learning to Live with a Powerful Species Preservation Law,* 62 U. COLO. L. REV. 109, 109 (1991) (describing § 9 of the ESA as "simple, unambiguous, and breathtaking in its reach and power"); Albert Gidari, *The Endangered Species Act: Impact of Section 9 On Private Landowners,* 24 ENVTL. L. 419, 426-43 (1994) (evaluating the effect of § 9 on landowners through the example of the Northern Spotted Owl); Kilbourne, *supra* note 135, at 572-84 (analyzing section 9 of the ESA and the regulatory definition of "harm"); Steven P. Quarles et al., *Sweet Home and the Narrowing of Wildlife "Take" Under Section 9 of the Endangered Species Act,* 26 Envtl. L. Rep. (Envtl. L. Inst.) 10003, 10003-04 (1996) (analyzing § 9 of the ESA in light of Babbitt v. Sweet Home Chapter of Communities for a Great Oregon, 515 U.S. 687 (1995)).

141. *See* Policy Regarding the Recognition of Distinct Vertebrate Population Segments Under the Endangered Species Act, 61 Fed. Reg. 4722, 4723 (1996). There is increasing evidence that the number of genetically distinct populations of a species is an important factor in the species's sustainability. *See* Jennifer B. Hughes et al., *Population Diversity: Its Extent and Extinction,* 278 SCIENCE 689, 689-91 (1997).

142. Policy Regarding the Recognition of Distinct Vertebrate Population Segments Under the Endangered Species Act, 61 Fed. Reg. 4722, 4723 (1996).

listing decisions, because they believe the ESA "is not intended to establish a comprehensive biodiversity conservation program, and it would be improper for the Services to recognize a potential [population] as significant and afford it the Act's substantive protections solely or primarily on these grounds."[143]

The agencies' decisions on these points, both of which are legally accurate, illustrate the reductionist boundaries of the ESA in its current form. Decisions must be made only about the species, based only on the status of the species, and only on behalf of the species. The example of the Snow Goose population explosion, which is now threatening ecosystems upon which other species depend, illustrates the folly of the reductionist approach.[144] Species-based decisions might incidentally involve consideration of ecosystem-level conditions and lead incidentally to ecosystem-level protection, but the ESA definitely is not the Endangered *Ecosystem* Act.

Nevertheless, the ESA provides a classic example of the power of reductionism and its intoxicating effect on our perception of the world. Many commentators continue to advocate that the species-specific approach to conservation policy is superior to broader ecosystem-based models, particularly when an individual species can be identified to serve as a surrogate for management of larger ecosystems.[145] These so-called "indicator species" represent precisely the kind of reductionist shortcut that has proved so successful in classical science as a means of approximating reality. But they are not reality, and as ecosystem-wide degradation becomes an increasingly real threat, these fabrications will increasingly serve less useful to reaching sound management decisions.

The central flaw in the indicator species approach is that it relies on a linear-causal approach to problem solving, an approach that is deeply ingrained in our culture and affects the way in which we conceptualize reality.[146] The premise is simple: if the indicator species is in decline, it is because of degradation of the ecosystem. Therefore, if we can reverse the decline of the indicator species, the ecosystem will improve as well.[147] That

143. *Id.* at 4724.

144. *See Snow Goose Population, supra* note 94, at <http://www.fws.gov-1>

145. *See, e.g.*, Oliver A. Houck, *On the Law of Biodiversity and Ecosystem Management*, 81 MINN. L. REV. 869, 960 (1997) (advocating the species-specific approach as "objective, science based and enforceable").

146. *See* Ted Lumley, *Complexity and the "Learning Organization,"* COMPLEXITY, May-June 1997, at 14, 14-16.

147. For a general discussion of the deficiencies of using the linear-causal approach in management decisions for complex adaptive systems, see Lumley, *supra* note 146, at 14-15.

approach works reasonably well for systems whose components are only weakly and linearly coupled; but, in complex adaptive systems, the linear-causal approach "delivers seriously flawed views and solution approaches."[148] Thus, while the indicator species approach has gotten us far in ecosystem conservation because of its shortcut qualities, it is proving increasingly flawed both biologically and politically as the pressure on ecosystems *as ecosystems* increases.[149]

The problem with the indicator species approach biologically is that it leads to a static view of ecosystems. The fact that a species acts as an indicator of the health of an ecosystem does not necessarily mean that the species's health is essential to the health of the ecosystem, or even that the ecosystem for which it serves as an indicator is a particularly desirable one in terms of the species community and ecosystem functions.[150] Once we pick the indicator species in an ecosystem and base management decisions on that species's continued viability, we have necessarily short-circuited the adaptive processes in the ecosystem.[151] If we prop up one species, other species may suffer, and why should they? As we preserve the "snapshot" ecosystem needed to support the indicator species, have we precluded other species assemblies that would have been brought about as a result of nonlinear responses to environmental disturbance regimes (flood, fire, drought)? How do we decide at which point to paralyze the ecosystem dynamics in the name of preserving the static ecosystem state of choice? The indicator species approach requires answers to these questions, questions that do not make sense if we view ecosystems as complex adaptive systems.

148. *Id.* at 22.

149. *See* Houck, *supra* note 145, at 954-59 (recognizing the political and biological disputes over the indicator species approach).

150. Species that are essential to the dynamic health of the ecosystem, but which do not necessarily act as indicators of the health of any particular single state of the ecosystem, are known as "keystone species." *See* F. Stuart Chapin III et al., *supra* note 62, at 501 (claiming that "keystone species" have "effects that are substantially greater than one would expect"). Managing for the support of keystone species, because they are more directly related to the ecosystem functions, may prove superior to the indicator species approach as a means of ecosystem management. Recent research indicates, however, that most species individually are not critically important to the continuing diversity of biological evolution. *See* Sean Nee & Robert M. May, *Extinction and the Loss of Evolutionary History*, 278 SCIENCE 692, 692-94 (1997)

151. For example, in ecosystems where species compete and thus fluctuate in numbers according to complex predator-prey cycles, managing to support any one species can have serious effects on the others. *See* Louis W. Botsford et al., *The Management of Fisheries and Marine Ecosystems*, 277 SCIENCE 509, 511 fig.3 (1997) (providing the example of limiting takes of a conch in an intertidal ecosystem in Chile that led to the decline of a mussel species and the rise of three species of barnacles).

To be sure, despite its flawed portrayal of ecosystem dynamics, the indicator species approach may provide the political muscle for preventing adverse human disturbance of the ecosystem and thus justify the artificially imposed stasis of the ecosystem.[152] But this political justification is becoming increasingly tenuous as well, as it focuses public attention and debate on the fate of species rather than of ecosystems. When the species is insignificant in the public's eye—such as a fly, a snail, or a beetle—it becomes difficult to portray the underlying ecosystem as significant. Indicator species might provide a means to "convene the meeting and draw a bottom line,"[153] but when the meeting is about a fly and only a fly, the bottom line might not get us where we would otherwise want to be on behalf of the ecosystem.[154] If we want people and the political processes in which they participate to be concerned with ecosystems, we should develop legal frameworks that provide relevant information and decision making contexts. Hence, it is not that those who advocate a broader ecosystem approach in favor of the indicator species approach "simply have not opened their eyes,"[155] but rather that they are looking past the fabricated solutions for the real answers.

2. Linearism. We know that the complex webs of ecosystems lead to species-level population dynamics that fluctuate chaotically based on natural and anthropogenic disturbances.[156] Nevertheless, the picture one receives from the ESA is of a linear process of species decline and, through ESA intervention, improvement—a down escalator and an up escalator.

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152. *See* Houck, *supra* note 145, at 959-60 (claiming that "the ESA provides the muscle for the discussions" between developers, planners, and environmentalists and asserting that ecosystem planning efforts have come about "through the use of indicator species").

153. *Id.* at 959.

154. An excellent example of this failure of the indicator species approach politically is the Delhi Sands Flower loving fly, an indicator species for Delhi Sands ecosystem formations in southern California, the listing of which lowered the heavy hand of ESA protection on several communities suffering from persistent unemployment and economic stagnation. Asking those communities to sacrifice important public works projects and much-needed economic development projects in order to save a fly simply did not sit well with the local community. *See* Thomas C. Jackson, *Sustainable Development and the Endangered Species Act*, __ NAT. RESOURCES & ENV'T __ (forthcoming) (draft on file with the *Houston Law Review*). As a result, any talk today of the importance of managing the dwindling Delhi Sands ecosystem as a whole is unlikely to engender much public support—it is more likely to be remembered as simply "fly habitat."

155. Houck, *supra* note 145, at 959.

156. *See* Brown, *supra* note 1, at 421-32 (describing how species diversity leads to networks of interations and food webs).

Species that are thriving do not count under the ESA. Once a species is in decline, the ESA treats it as a "candidate" for listing, though no protections apply to such species.[157] Once a species is "likely to become an endangered species within the foreseeable future," it is "threatened."[158] Then, when the species "is in danger of extinction throughout all or a significant portion of its range," it is "endangered."[159] Recovery plans are designed to turn that linear decline process around and to send the species on the up escalator.[160]

It is difficult to fit emerging biological concepts of critical minimum viable populations and habitats into that gradualist vision of species. A species may appear to be thriving but in fact be in deep peril, or vice versa.[161] Who would have known, for example, that the tambalacoque tree was "endangered" the moment the dodo went extinct?[162] Biology simply is not linear in the sense that the ESA suggests. Hence, as Professor Jonathan Baert Wiener states: "Law cannot require 'a balance of flora and fauna' not because it would be too difficult, but because the term is meaningless: populations of various organisms are perpetually in flux, landscapes change, climates change, and definitions of species and ecosystems change."[163]

3. *Predictivism.* Inherent in the ESA is the assumption that we can predict the fate of species and the effects of both positive

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157. *See* 16 U.S.C. § 1535(d)(1) (1994).

158. *Id.* § 1532(20).

159. *Id.* § 1532(6).

160. *See id.* § 1533(f) (requiring the development of recovery plans for the conservation and survival of endangered and threatened species).

161. As biologists increasingly face this amorphous state of affairs, they have found it increasingly difficult to provide policy advice relevant to the ESA framework. The typical policy prescription in conservation biology circles is to say simply that "maintaining as much wild land as possible is the most viable option." Michael J. Samways, *The Art of Unintelligent Tinkering*, 10 CONSERVATION BIOLOGY 1307, 1307 (1996). Some conservation biologists concede, however, that this is not a very helpful policy guideline as it suggests no end boundary to preservation. *See* John M. Hagan, *Environmentalism and the Science of Conservation Biology*, 9 CONSERVATION BIOLOGY 975, 975 (1995) (conveying the conflicting emotions and thoughts of a conservation biologist). The central problem in defining such a boundary is that "the relationship between socioeconomic factors and biodiversity loss is not well understood." Deborah J. Forester & Gary E. Machlis, *Modeling Human Factors That Affect the Loss of Biodiversity*, 10 CONSERVATION BIOLOGY 1253, 1253 (1996). Hence, "[p]resently there is no method to determine how much land should be protected to maintain an ecosystem's integrity." Steven R. Beissinger et al., *Null Models for Assessing Ecosystem Conservation Priorities: Threatened Birds as Titers of Threatened Ecosystems in South America*, 10 CONSERVATION BIOLOGY 1343, 1344 (1996).

162. Refer to note 88 *supra* (relating the mutualistic relationship between the tambalacoque tree and the dodo).

163. Jonathan Baert Weiner, *Beyond the Balance of Nature*, 7 DUKE ENVTL. L. & POL'Y F. 1, 11 (1996).

and negative human intervention. A species is considered "threatened" when it is "likely" to become endangered.[164] It is classified as "endangered" when it is "in danger of extinction."[165] A recovery plan must detail "site-specific management actions" and state "objective, measurable criteria" that will tell us when to remove the species from the list.[166] An action constitutes a prohibited "take" if it will foreseeably lead to the death or injury of a protected species.[167]

To many biologists these must be nonsensical undertakings worth pursuing only because there is no other mechanism available in current law for translating biological science into policy. Take the case of the Spruce-fir Moss spider, a small spider endemic to high-elevation eastern spruce-fir forests and threatened by forest desiccation caused by, among other things, acid precipitation.[168] Predicting the species's future status requires predicting the effects of sulfur dioxide emission regulations, the complex effects of declining atmospheric dusts and atmospheric acid levels, and the combination of both over eastern forests. The species recovery depends little on site-specific actions. The acid rain emanates from dispersed actions taken far away and can only be measured based on factors such as the average annual rainfall and amount of sunlight reaching rock surfaces. Those conditions are difficult to predict reliably. The reality is that we will know the spider is endangered when we cannot find many of them. Alternatively, we will know that it is recovered if we find a lot of them, assuming we know where and when to look for them. Beyond that, prediction under the ESA is a dangerous game.

B. The Shortcomings of Current Reform Models

It has become almost a cliché to point out that environmental law keeps changing. The question is whether any of that change responds meaningfully to change in the subject matter of environmental law. For example, adding species to the ESA list of endangered species is a change in environmental law, but the fact that we keep adding endangered species to the list suggests the ESA is not adequately addressing the causes of ecosystem

164. 16 U.S.C. § 1532(20).

165. *Id.* § 1532(6).

166. *Id.* § 1533(f)(1)(B)(i)-(ii).

167. *See* Babbitt v. Sweet Home Chapter of Communities for a Great Or., 515 U.S. 687, 696-98 & n.9 (1995) (stating that the regulations do not cover consequences that are not foreseeable).

168. *See* Endangered and Threatened Wildlife and Plants: Proposal to List the Spruce-Fir Moss Spider as an Endangered Species, 59 Fed. Reg. 3825, 3825-26 (1994).

degradation. Nevertheless, although almost no one denies the need for more change in environmental law, very few proposals for implementing reform demonstrate an appreciation of complex adaptive systems as a model. Instead, the two dominant conflicting reform models advocate incremental change on the one hand and wholesale deregulation on the other. The former involves mere baby steps around the fitness landscape; while the latter is a deluded attempt to reverse the system and return to simpler times.

1. The Weak Reform Model: The Mirage of "Reinvention" Rhetoric. One of the most active and concerted reform efforts in environmental law is taking place through the Clinton Administration's overhaul of ESA administrative policies and programs. In 1994, the Departments of Interior and Commerce, which implement the ESA through the FWS and the NMFS respectively, launched an effort to overhaul the ESA without waiting for Congress to lead.[169] The agencies responded to the same two themes that have fueled the reauthorization debate in Congress. On the one hand, the message from biologists increasingly is that effective species conservation requires a focus that goes beyond individual species to protection and management of whole ecosystems.[170] On the other hand, property rights advocates have increasingly claimed that the ESA runs roughshod over business and landowner interests to protect critters of little economic value.[171] The problem, as I have demonstrated, is that neither of those concerns is addressed satisfactorily in the existing ESA.

The agencies' administrative reform of the ESA began in March 1994 with FWS's publication of *An Ecosystem Approach to Fish and Wildlife Conservation: An Approach to More Effectively Conserve the Nation's Biodiversity.*[172] The agency portrayed this

169. Actually, it may have been a nudge by the judiciary that spurred the effort. In response to the court's ruling in *Pacific Rivers Council v. Thomas,* 30 F.3d 1050 (9th Cir. 1994), the FWS and the NMFS published a proposed rule to establish "alternative" regulations called the Joint Counterpart Endangered Species Act Section 7 Consultation Regulations, 60 Fed. Reg. 39,921 (1995) (to be codified at 50 C.F.R. pt. 402).

170. The joint consultation regulations are intended to "provide a framework for consultation on program-level or ecosystem-level decisions, as opposed to project-level decisions." Joint Counterpart Endangered Species Act Section 7 Consultation Regulations, 60 Fed. Reg. 39,921 (1995) (to be codified at 50 C.F.R. pt. 402).

171. *See* Jonathan H. Adler & Kelly Anne Fitzpatrick, *For the Environment, Against Overregulation,* WALL ST. J., July 29, 1996, at A12.

172. U.S. FISH & WILDLIFE SERV., U.S. DEP'T OF INTERIOR, AN ECOSYSTEM APPROACH TO FISH AND WILDLIFE CONSERVATION: AN APPROACH TO MORE EFFECTIVELY CONSERVE THE NATION'S BIODIVERSITY (1994).

policy document as its road map for applying "the concept of managing and protecting ecosystems to everything the Service does."[173] The agency thereby explicitly endorsed the emerging goal of protection and management of whole ecosystems. The second reform track was launched one year later, with FWS's publication of *Protecting America's Living Heritage: A Fair, Cooperative and Scientifically Sound Approach to Improving the Endangered Species Act.*[174] This document outlined the agency's plan to "provide effective conservation of threatened and endangered species and fairness to people through innovative, cooperative, and comprehensive approaches."[175] Recently the two agencies jointly published a policy statement emphasizing opportunities to merge and harmonize the two agendas through measures that serve both interests.[176] To be sure, there is a risk of overselling the degree to which the "ecosystem approach" and "fair approach" agendas can be merged. At some points the issue of species conservation really does come down to choosing between conflicting constraints. But the agencies should be given credit for inventing some truly ground-breaking approaches[177] that have gotten former enemies on speaking terms.

173. *Id.* at 5.

174. U.S. FISH & WILDLIFE SERV., U.S. DEP'T OF INTERIOR, PROTECTING AMERICA'S LIVING HERITAGE: A FAIR, COOPERATIVE AND SCIENTIFICALLY SOUND APPROACH TO IMPROVING THE ENDANGERED SPECIES ACT (1995).

175. *Id.* at 1.

176. *See* U.S. FISH & WILDLIFE SERV., U.S. DEP'T OF INTERIOR, & U.S. NAT'L MARINE FISHERIES SERV., U.S. DEP'T OF COMMERCE, MAKING THE ESA WORK BETTER: IMPLEMENTING THE 10 POINT PLAN ... AND BEYOND 2 (1997) (discussing the significant progress made by the cooperative efforts of the federal agencies toward protecting species earlier and more efficiently than ever).

177. An example of the agencies' innovative approach is found in the proposed "Safe Harbor" program introduced as a way of providing incentives for landowners to maintain or enhance their land as a home to listed species. *See* Announcement of Draft Safe Harbor Policy, 62 Fed. Reg. 32,178, 32,178 (1997). While a landowner may not injure a listed species, either directly or indirectly by destroying its essential habitat, without express take authorization from the agencies, nonfederal landowners have no duty to expand habitat or otherwise improve the condition of a listed species. *See id.* And why would they, unless they desire expanded land use restrictions? Under the Safe Harbor policy, however, the agencies are "providing an incentive to property owners to restore, enhance, or maintain habitats resulting in net conservation benefit to endangered and threatened species." *Id.* at 32,179. Landowners who improve conditions for listed species under a Safe Harbor agreement will receive a permit providing assurance that the landowner may implement land uses in the future so long as those uses do not degrade the species population and habitat below baseline levels in existence on the property before the permit is issued. *See* Safe Harbor Agreements and Candidate Conservation Agreements, 62 Fed. Reg. 32,189, 32,190-92 (1997) (describing proposed amendments to 50 C.F.R. § 17.22). For comprehensive reviews of this and other specific measures the agencies have promulgated to implement the reform agendas, see J.B. Ruhl, *While the Cat's Asleep—The Making of the "New" Endangered Species Act*, 12 NAT. RESOURCES & ENV'T __ (forthcoming) (draft on file with the *Houston Law Review*); J.B. Ruhl, *Who Needs*

Nevertheless, these efforts must be placed in the larger context of the ESA, the provisions of which act as a niche limiting how far the agencies can go toward adaptive solutions.[178] Already some courts have chastised the agencies for experimenting in ways the courts have found to cross beyond what the ESA permits.[179] In essence, the ESA has constrained the boundaries of the fitness landscape for ecosystem conservation policies and limited us to walking across that boxed-in landscape in search of fitter solutions. It is commendable that the agencies have embarked on that walk, but it would be folly to believe that the agencies will reach a solution that responds to the highly complex land-use system dynamics that are leading to increased local and global pressure on ecosystems. Walking the landscape within a tightly defined niche can lead to temporary fixes; real reform requires breaking out of the box.

2. The Absurdly Strong Reform Model: Disaster Through Deregulation. One of the dangers of opening the ESA reform discussion sufficiently wide to make long fitness landscape jumps possible is that it appears to lend some credence to the wholesale deregulation reform model. The deregulation approach assumes that because the ESA has not solved the ecosystem degradation problem, removing the ESA will. Thus, for example, some recent ESA reform bills introduced in Congress would have abandoned the existing ESA structure altogether and replaced it with a program designed to induce desirable landowner behavior through tax and subsidy incentives.[180] The Cato Institute has advocated even more sweeping deregulation, proposing that we base federal biodiversity conservation solely on "noncoercive market processes."[181] But while eliminating the ESA and putting essentially nothing but the market in its place would result in a

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Congress?—An Agenda for Administrative Reform of the Endangered Species Act, 6 N.Y.U. ENVTL. L.J. __ (forthcoming) (draft on file with the *Houston Law Review*).

178. As illustrated in the Draft Safe Harbor Policy announcement, the FWS and the NMFS cannot mandate or require under the ESA private land owners to manage their property to the benefit of endangered species. *See* Announcement of Draft Safe Harbor Policy, 62 Fed. Reg. at 32,178.

179. *See, e.g.*, Defenders of Wildlife v. Babbitt, 958 F. Supp. 670, 679-80 (D.D.C. 1997) (finding that in deciding not to list a species, the FWS relied on a standard that "contrasts starkly" with the standard mandated by the ESA).

180. *See* H.R. 2364, 104th Cong. § 2 (1995) (stating that the United States should provide incentives for both state and private efforts to "create, maintain, and implement effective endangered species programs").

181. Allan K. Fitzsimmons, *Federal Ecosystem Management: A "Train Wreck" in the Making*, POL'Y ANALYSIS, Oct. 26, 1994, at 1, 23.

long jump across the fitness landscape, this approach ignores several other important features of complex systems.

The fundamental mistake of the deregulation approach is that it is based on the same linear-causal problem solving approach that has shaped the ESA itself. The premise is that the ESA is not simply part of the problem, but that it *is* the problem.[182] What is abundantly certain, however, is that it is delusional to believe that deregulation will somehow turn back the clock to a time when neither ecosystem degradation pressures nor property rights concerns were acutely in conflict as they are today. The fact that the ESA is not effectively resolving that conflict does not mean that it has caused the conflict or that reeling in the ESA will move us back along the time line over which the conflict has evolved. Indeed, there is nothing we can do to reverse the nonlinear co-evolution of ecosystems, technology, economies, and land use that has led to the ecosystem degradation problem. All we can do is change, and we hope thereby to improve, the direction in which the problem-solving process is headed.

Would wholesale deregulation improve the direction of ecosystem conservation policy? Maybe. The possibility cannot be ruled out. But the elimination of law from the solution to this or any problem of environmental law should be used only if we are reasonably convinced, first, that law itself cannot be reorganized to work more adaptively toward solutions to the problem, and second, that doing so would not improve the capacity for adaptive social responses above that which exists through other systems such as the market, public education, and so on. In other words, we should recognize that we have more than law at our disposal and that the presence of other social problem-solving mechanisms does not mean that law cannot work adaptively to improve the overall fitness of our solutions. The incremental reform model puts all the emphasis on law in a static state, refusing to experiment not only with law, but also with other social problem-solving systems.[183] The deregulation model puts all the emphasis on the other social problem-solving systems, using law only as an adjunct for putting them in motion.[184] The problem with the deregulation model, therefore, is that it prevents us, just as much as does the incrementalist model, from deliberately trying to make long jumps through focused legal reform. In short, neither of the prevailing reform models permits us to think of environmental law as a complex adaptive system.

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182. Refer to note 180 *supra* and accompanying text.
183. Refer to notes 169-77 *supra* and accompanying text.
184. Refer to notes 180-81 *supra* and accompanying text.

IV. THUS, ENVIRONMENTAL LAW MUST BE REVOLUTIONIZED WITH COMPLEX ADAPTIVE SYSTEMS AS ITS MODEL

Environmental law has hit the same wall into which science in general has slammed—the last five percent of the problems are the hardest to solve.[185] Conventional reductionist methods and linear models have taken us far in both realms, solving the first ninety-five percent of the problems with tremendous efficiency,[186] but both incremental additions to and wholesale abandonment of that approach seem to lead in the wrong direction. The last five percent will require a revolution in the design of environmental law.

It is one thing to recognize that ecosystems, technology, economies, and land use behave as complex adaptive systems[187] and that environmental law cannot treat them as anything else. It is quite another thing to ask how environmental law itself must be designed *as a system* given that reality. Law is one of society's problem-solving mechanisms. As complex adaptive systems research has demonstrated, however, it is very difficult to solve problems in such systems unless you think like a complex adaptive system. I posit, therefore, that the environmental law we use to address the problems of the future in environmental quality must itself incorporate the qualities of its subject matter—in other words, we *must* think of environmental law as a complex adaptive system.

A. *The Key Design Questions—A Plan for the Revolution*

The starting point in the reform process is to ask the relevant questions. The prevailing environmental law reform models fail to address the fundamental set of complex adaptive system design issues. The incremental reform model involves timid, highly planned walks around the existing landscape, testing for only slightly higher fitness peaks while in fact all nearby peaks are eroding because the rest of the world is changing rapidly. The deregulation model puts all the marbles into one long distance landscape jump, but as a roll of the dice rather than with conscious deliberation as to direction and distance. A long jump is needed, but what is also needed, and what humans have the advantage of being capable of conceiving, is a plan for the revolution.[188]

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185. Refer to note 13 *supra* and accompanying text (describing the limits of reductionist science).

186. Refer to note 13 *supra* and accompanying text.

187. Refer to Part II.B *supra* and accompanying text.

188. Gerald Emison's proposed design questions, derived as well from complex

1. Aggregation: Centralization, Devolution, or Something Else? To talk intelligently of the environmental law decision making system, we must begin by questioning the system's component structure. Environmental law and policy decisions are essentially the emergent properties of the interactions of the system's decision making components, and, thus, design choices regarding the "patchiness" and "coupledness" of the components are critical. The sense of the importance of those questions is almost instinctive in our constitutional system of government.[189]

It is no surprise, therefore, that a central and raging debate in environmental law focuses on the balance of power between state and federal governments and the merit of the system of so-called "cooperative federalism" that has been in place for twenty-five years and under which the federal government has taken the policy-shaping and standard-setting role for the states and their local subdivisions.[190] That debate, however, largely ignores

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systems analysis, strike at similar themes: (1) Is it a system in which the components interact in a complicated manner?; (2) Is the system non-linear and dynamic?; (3) Is emergence a property of the system?; and (4) Is the system self-similar? *See* Emison, *supra* note 14, at 182-86. The difference between his formulation and mine is that mine focuses more on the structural characteristics that lead to the behaviors he identifies; nevertheless, clearly we are aimed in the same direction.

189. *See* Ruhl, *Fitness of Law*, *supra* note 15, at 1467-88.

190. *See, e.g.*, Henry N. Butler & Jonathan R. Macey, *Externalities and the Matching Principle: The Case for Reallocating Environmental Regulatory Authority*, 14 YALE L. & POL'Y REV./YALE J. ON REG. 23, 24 (1996) (considering whether environmental policy can be improved by reallocating authority for regulation within the federal system); A. Dan Tarlock, *Federalism Without Preemption: A Case Study in Bioregionalism*, 27 PAC. L.J. 1629, 1629-30 (1996) (describing a new federalism by which the federal government protects biodiversity without the actual displacement of state law). Some commentators argue that "cooperative federalism" has stifled potentially innovative state approaches. *See, e.g.*, Adam Babich, *Our Federalism, Our Hazardous Waste, and Our Good Fortune*, 54 MD. L. REV. 1516, 1540 (1995) (observing that "[f]or states, [the] cooperative federalism program is part of a pattern of complexity that has generally prevented them from attempting significant innovations"); Oliver A. Houck & Michael Rolland, *Federalism in Wetlands Regulation: A Consideration of Delegation of Clean Water Act Section 404 and Related Programs to the States*, 54 MD. L. REV. 1242, 1251-53, 1301-13 (1995) (explaining why the costs and complexity of delegation of federal wetlands protection programs have deterred states from assuming such authority and calling for revisions which would provide the states greater jurisdictional authority); Jerome M. Organ, *Limitations on State Agency Authority to Adopt Environmental Standards More Stringent Than Federal Standards: Policy Considerations and Interpretive Problems*, 54 MD. L. REV. 1373, 1376-93 (1995) (explaining that many states, partially in response to the complexity of the federal program, simply adopt the federal standards as the maximum state standard and leave it at that, thus suppressing any impetus to innovate). Others are of the position that the dominant federal position should be retained. *See, e.g.*, Kirsten H. Engel, *State Environmental Standard-Setting: Is There a "Race" and Is It "To the Bottom"?*, 48 HASTINGS L.J. 271, 279-80 (1997) (arguing that interstate competition for economic development and environmental benefits absent federal supervision would be detrimental to social welfare and cause a "race-to-the-bottom");

the qualities that complexity theory suggests are needed in adaptive systems. To be truly adaptive, the environmental law system must be able to operate with many coupled patches arrayed on a variety of nested, coupled levels of organization, including levels intermediate in structure to the bottom (local) and top (federal) of the system. This permeable, nested hierarchy approach is not contemplated by the local-versus-state-versus-federal debate that dominates the "cooperative federalism" design model.

In short, entirely new forms of organizational structures are needed in order to match environmental law with the complexity of its subject matter. Watersheds, for example, exist in a nested hierarchy, open system form: small-scale watersheds (a drainage ditch fed intermittently by runoff from several farms) feed into local watersheds (a perennial stream) that feed into larger regional watersheds (a river tributary) that feed into enormous multistate and multinational watersheds (the Colorado River).[191] Protection of ecological and economic interests associated with watersheds, therefore, will require greater reliance on interlocal organizations, interstate compacts, regionally-oriented autonomous federal agencies, and partnerships between all of those as well as nongovernmental organizations and landowners. These forms of political organization are constitutionally permissible, but have been mostly untested and underused.[192]

Robert Housman, *The Devil Is In the Exogenous Variables*, ENVTL. F., May-June 1996, at 32, 33 (advocating, from an international environmental lawyer's perspective, a dominant federal position); Vickie L. Patton, *A Balanced Partnership*, ENVTL. F., May-June 1996, at 16, 17 (arguing, as an attorney for the Environmental Protection Agency, in favor of retaining dominant federal position). It is difficult to ignore the emergence in recent years of a "devolution" sentiment in American society. For example, although public support for strong environmental protection policies remains high, polls suggest that increasingly the public wishes the actual policy decision making to be the responsibility primarily of state and local governments. *See* Jonathan H. Adler & Kellyanne Fitzpatrick, *For the Environment, Against Overregulation*, WALL ST. J., July 29, 1996, at A12 (stating that 65% of those polled favor state or local responsibility); *Americans Favor State, Local Controls, Poll Says*, 27 Env't Rep. (BNA) 801, 801 (1996) (stating that "[m]ost Americans believe that states and local governments would do a more efficient job in addressing environmental concerns than the federal government").

191. *See* U.S. GEN. ACCOUNTING OFFICE, GAO/RCED-94-111, ECOSYSTEM MANAGEMENT: ADDITIONAL ACTIONS NEEDED TO ADEQUATELY TEST A PROMISING APPROACH 42-44 (1994) (discussing the spatially interlinked nature of watersheds and other landscape features and the challenges that poses to legal responses).

192. *See* J.B. Ruhl, *Interstate Pollution Control and Resource Development Planning: Outmoded Approaches or Outmoded Politics?*, 28 NAT. RESOURCES J. 293, 308-09 (1988) (discussing the failure of the federal and state governments to give life to interstate compacts designed to address regional water pollution).

It is time we "reinvent" environmental law, therefore, not simply by tinkering with the familiar landscape, as is too frequently what lies behind calls for reform, but by making a long jump to these new domains. To do so, the local, state, and federal structures must combine their "genes," engage in the political equivalent of sex, and make the environmental law governance system messy in the complex adaptive systems sense.[193] To be sure, this new approach will result in political processes that are amorphous, costly, painful, and that require hard work. However, that investment will improve our chances of cleaning up the environmental mess we have created in the usual sense of the word.[194]

2. Flows: Is the Market Friend or Foe? What medium is flowing through environmental law's pipes? What does the environmental law system consume and convert into its main product—legal and policy decisions? Clearly the answer, as it is for many human systems, is information: information about environmental conditions and trends, about social behaviors and trends, about anthropogenic impacts on the environment, about effectiveness of and compliance with law, and so on. Environmental law decision making relies primarily on having those bodies of information available in relevant, analyzable forms. Therefore, the flow design question becomes how to allow the system to efficiently obtain and make the best use of those bodies of information.

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193. An example of such an approach is found in the Ozone Transport Assessment Group ("OTAG"), a coalition of 37 eastern states that formed to negotiate solutions to the interstate atmospheric transport of ozone precursor air pollutants. *See* John Pendergrass, *OTAG Opens New Vistas Among States*, ENVTL. F., Jan.-Feb. 1997, at 5, 5. One of the thorny issues that had divided the states, and which EPA had been unable to resolve, was what transport model to use. Once OTAG was formed, the states eventually put aside their regional preferences, developed a modeling and information analysis method far superior to what EPA or any single state had been using, and formulated concrete strategy options. *See id.; see also OTAG Report Paves Way for More Cuts in Emissions from Utilities, Officials Say*, 28 Env't Rep. (BNA) 399, 399 (1997). The OTAG states are not in complete harmony, however, as eastern state members have brought proceedings against midwest state members to force reductions in emissions by the latter. *See* John Pendergrass, *When Northeast Meets Midwest*, ENVTL. F., Sept.-Oct. 1997, at 6, 6.

194. Several commentators have begun thoughtfully to open the reform debate wider in this respect, focusing on the need to "find the best fit possible between environmental problems and regulatory responses—not to pick a single level of government for all problems." Daniel C. Esty, *Revitalizing Environmental Federalism*, 95 MICH. L. REV. 570, 574 (1996) (footnote omitted). In particular, Professor Errol Meidinger has explored the issue from a systems perspective, observing that many of the emerging environmental law problems are largely organizational problems. *See* Errol E. Meidinger, *Organizational and Legal Challenges for Ecosystem Management*, *in* CREATING A FORESTRY FOR THE 21ST CENTURY 361-79 (Kathryn A. Kohm & Jerry F. Franklin eds., 1997).

We have seen two models of information flow thus far in modern environmental law. First, prior to the 1970s, the common law served as the primary environmental law system framework, and thus information flowed principally through the channels of the common law processes.[195] The problem with that model, however, was that despite the adaptive nature of the common law generally, that system was not particularly well suited to obtaining and analyzing information relevant to the environmental policy realm.[196] Its reliance on plaintiffs claiming and proving injury to property or person imposes filters and cost constraints that narrow the diameter of the information flow pipes to the point at which the common law simply does not fit well with such system-level issues as management of ecosystems, prevention of risk, and acid rain deposition. The statutorification of environmental law beginning in the 1970s, with its heavy emphasis on the federal administrative state, widened the pipes by shifting responsibility for information flows to agencies as repositories of expertise and analytical power.[197] But, unlike the common law, the administrative state has not proven to be a highly adaptive system, and thus has managed to clog the information flow pipes with the idiosyncrasies of bureaucracies that are fundamentally reductionist in organization, linearist in perspective, and predictivist in purpose.[198]

The shortcomings of the common law and administrative state models have led many commentators to observe that the market may serve as an efficient information flow mechanism for environmental law.[199] Unlike the common law, with relatively

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195. For a discussion of the evolution of the common law into and out of being the dominant medium of environmental regulation, see Ruhl, *Fitness of Law*, *supra* note 15, at 1454-62.

196. *See id.* at 1459 (explaining, for example, that the common law nuisance cause of action was based on protection of private property).

197. *See id.* at 1462.

198. *See id.* at 1463-88 (arguing that although the administrative state has achieved success in environmental protection, the premises upon which such successes were based do not remain valid forever and policy, too, must evolve).

199. The need for even greater reliance generally on market forces to bring about more efficient protection of environmental factors has been forcefully argued by many commentators. *See, e.g.*, Bruce A. Ackerman & Richard B. Stewart, *Reforming Environmental Law: The Democratic Case for Market Incentives*, 13 COLUM. J. ENVTL. L. 171, 171 (1988) (arguing that the creative use of market incentives will save billions of dollars each year, alleviate bureaucratic measures, help balance the budget, and encourage a more democratic debate by providing the public with an opportunity to express their environmental values); Daniel J. Dudek et al., *Environmental Policy for Eastern Europe: Technology-Based Versus Market-Based Approaches*, 17 COLUM. J. ENVTL. L. 1, 9 (1992) (stating that Eastern Europe should adopt market-based approaches because they encourage businesses and consumers to avoid products associated with pollutants which reflect added costs and because such an approach also allows businesses to retain flexibility in the methods they

low marginal transaction costs, the market's pipes will open as wide as we want to accept information we deem relevant to environmental law and policy decision making. Unlike the administrative state, the market as a system is highly adaptive and open ended—the difficulty is not in our inventing it, but in our not getting in its way.[200] It provides the best of both worlds—it is sufficiently flexible to accept information however packaged and is sufficiently adaptive to transport the information to wherever it is needed even as the needs and destinations change.[201]

In this sense the market may be environmental law's best friend, or its worst foe. The difference will lie in how active a role environmental law takes in using the information flow role of the market to serve environmental law's needs. A complete hands-off approach may risk failing to identify and address environmental externalities and other market imperfections; an overbearing approach could stifle the advantages of the market. Several examples exist, however, of environmental law deftly either forcing information into the market[202] or creating the market conditions

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choose to avoid pollution); Robert W. Hahn & Gordon L. Hester, *Marketable Permits: Lessons for Theory and Practice*, 16 ECOLOGY L.Q. 361, 364-65 (1989) (stating that marketable permits have the potential to make environmental policy more efficient); Robert W. Hahn & Robert N. Stavins, *Incentive-Based Environmental Regulation: A New Era from an Old Idea?*, 18 ECOLOGY L.Q. 1, 10-11 (1991) (stating that "substantial gains can be made in environmental protection simply by removing existing government-mandated barriers to market activity"); Jeremy B. Hockenstein et al., *Crafting the Next Generation of Market-Based Environmental Tools*, ENVIRONMENT, May 1997, at 13, 15 (arguing that the two most notable advantages to market-based instruments are cost-effectiveness and incentives for technological innovation); Richard B. Stewart, *Reconstitutive Law*, 46 MD. L. REV. 86, 89 (1986) (arguing that the problem in many areas is federal regulation of the wrong sort rather than too little or too much federal regulation). *See generally* COMPETITIVE ENTER. INST., FREE MARKET ENVIRONMENTAL BIBLIOGRAPHY 3 (4th ed. 1995-96) (acknowledging the criticisms of conventional environmental policies and promoting an alternative to the current "government-knows-best" approach).

200. *See* PAUL KRUGMAN, THE SELF-ORGANIZING ECONOMY 2-7 (1996) (explaining how the "invisible hand" leads to order).

201. *See id.*

202. *See* Pub. L. No. 101-549, § 401, 104 Stat. 2399, 2584 (1990) (codified at 42 U.S.C. subch. IV) (stating that the "transferrability of allowances between units and to future years is the key both to the strong environmental policy sought in new Title IV of the Act and to the flexibility the Title creates for sources in choosing the means for complying with their emissions obligations"). The Clean Air Act sulfur dioxide emissions trading program for electric utilities, 42 U.S.C. §§ 7651-7651*o* (1994), is widely regarded as the most successful example of integration of market efficiencies into the command-and-control regulatory structure. *See, e.g.*, ROBERT V. PERCIVAL ET AL., ENVIRONMENTAL REGULATION 830-32 (2d ed. 1996); Dallas Burtraw & Byron Swift, *A New Standard of Performance: An Analysis of the Clean Air Act's Acid Rain Program*, 26 Envtl. L. Rep. (Envtl. L. Inst.) 10411, 10411 (1996) (calling the Acid Rain Program enacted as part of the 1990 Clean Air Act Amendments "one of the most successful environmental programs of the past decade"); Byron Swift, *The Acid Rain Test*, ENVTL. F., May-June 1997, at 17, 17 (reporting that

for information to flow.[203] In each case, success in achieving the intended environmental policies is visible.

3. Nonlinearity: Is Project XL Enough? How do we build into environmental law the capacity to deviate from order, to behave with nonlinear capacities? The existing environmental law regime gravitates toward a quantitative-based order of regulatory response with little room for variation. The Clean Air Act is built on a foundational premise of nationally uniform ambient air quality standards.[204] The Clean Water Act establishes national technology standards for emissions from specified types of facilities.[205] Room for deviation from the sameness of environmental standards is small, leading to a "McLaw" feel to environmental policy across the nation.

Recognizing that flexibility may breed progress, the Environmental Protection Agency ("EPA") has incorporated programs for deviation from the model of order with names such as

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the 1990 Clean Air Act's Acid Rain Program has significantly decreased the amount of sulfur dioxide emissions produced by public utilities); Timothy A. Wilkins & Terrell E. Hunt, *Agency Discretion and Advances in Regulatory Theory: Flexible Agency Approaches Toward the Regulated Community as a Model for the Congress-Agency Relationship*, 63 GEO. WASH. L. REV. 479, 491 (1995) (stating that the Clean Air Act Amendments of 1990 achieved the required reductions set out by policymakers at less cost to industry); *Utilities Achieve 100 Percent Compliance With EPA Acid Rain Program, Report Says*, 27 Env't Rep. (BNA) 885, 885 (1996) (stating that exceeding the 1995 emissions reduction goal demonstrates the benefits of providing flexibility to industry in achieving environmental goals). The program is nonetheless unmistakably part of the command-and-control regime, as the "market" for emission trading is created by regulatory fiat. *See* Roger K. Raufer, *Market-Based Pollution Control Regulations: Implementing Economic Theory in the Real World*, 26 ENVTL. POL'Y & L. 177, 184 (1996) (stating that "the market-based systems have relied heavily upon the command/control framework already in place").

203. For an example of the potential effectiveness of an information based approach to environmental regulation, companies subject to the toxic release reporting provisions of the Emergency Planning and Community Right-to-Know Act, 42 U.S.C. § 11023 (1994), reported the total release of 10.4 billion pounds of specified toxic chemicals into the environment in 1987, down to 2.8 billion pounds in 1993. *See* PERCIVAL, *supra* note 202, at 464-65. *See also Toxic Releases Cut By 400 Million Pounds, Chemical Manufacturers Association Reports*, 27 Env't Rep. (BNA) 501, 501 (1996) (discussing reductions in toxic releases between 1988 and 1994); *Toxic Chemical Releases Decrease By 8.6 Percent In 1994, Report Says*, 27 Env't Rep. (BNA) 531, 531 (1996) (stating that an 8.6% decrease in toxic chemicals represents a decrease of 186 million pounds of toxic chemicals). Industry sources attribute the reporting requirement as having galvanized industry into voluntary pollution reduction goals that in many cases exceed anything required by law. *See CMA Initiative Cuts Toxic Emissions 49 Percent Over Six Years, Official Says*, 27 Env't Rep. (BNA) 11, 11 (1996).

204. *See* 42 U.S.C. § 109 (establishing the program for promulgation of national ambient air quality standards).

205. *See* 33 U.S.C. § 1311 (1994) (setting up the program for promulgation of effluent pollution control technology standards).

"Project XL," the "Common Sense Initiative," "Enterprise for the Environment," and the "Environmental Leadership Program," which project an image of greater flexibility than found in the usual command-and-control programs.[206] Collectively known as "alternative path environmental management," the EPA and some outsiders have trumpeted them as amounting to a "reinvention" of the agency.[207] These pilot initiatives, however, generally have been difficult to sell to the rule-habituated stakeholders of environmental law. Environmental protection interests are fearful of the risks inherent in experimentation with flexibility,[208] and industry interests are fearful of the uncertainty of open-ended regulatory approaches.[209] So long as the safe harbor of the command-and-control model remains the nearby default position, its gravitational pull appears to be too strong to allow meaningful innovation through incremental and limited "alternative paths."

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206. *See* Regulatory Reinvention (XL) Pilot Projects, 62 Fed. Reg. 19,872 (1997); Regulatory Reinvention (XL) Pilot Projects, 60 Fed. Reg. 27,282 (1995); Common Sense Initiative Council Federal Advisory Committee, Establishment, 59 Fed. Reg. 55,117 (1994). *See generally* Camilla Day Buczek, *EPA Moves to Cooperative Approach*, NAT'L L.J., Oct. 14, 1996, at C13 (characterizing the EPA's new approach to environmental regulation a "common-sense" model grounded in sound science and economics).

207. *See, e.g.*, Timothy J. Mohin, *The Alternative Compliance Model: A Bridge to the Future of Environmental Management*, 27 Envtl. L. Rep. (Envtl. L. Inst.) 10345, 10345 (1997) (exploring a reinvention initiative called "alternative path environmental management," touted to be the antidote to the excessive bureaucracy of the current system); *What's All This About Reinvention?*, ENVTL. F., Mar.-Apr. 1997, at 34, 34 (surveying the EPA's reinvention efforts in both the private and public sector including the Reinventing EPA & Environmental Policy project and the Next Generation project). The EPA even has created a new Office of Reinvention. *See* Bud Ward, *Now At Bat*, ENVTL. F., July-Aug. 1997, at 38, 38 (profiling Chuck Fox, the associate administrator of the Office of Reinvention). Also, environmental policy think tanks have formed reinvention work groups. *See, e.g.*, NATIONAL ENVTL. POL'Y INST., REINVENTING EPA & ENVTL. POL'Y WORKING GROUP, INTEGRATING ENVIRONMENTAL POLICY (1996).

208. *See* Rena I. Steinzor, *Regulatory Reinvention and Project XL: Does the Emperor Have Any Clothes?*, 26 Envtl. L. Rep. (Envtl. L. Inst.) 10527, 10527-28 (1996) (arguing that Project XL is damaging the reputation of industrial self-regulation and ultimately "undermining EPA efforts to control and prevent pollution"); *Concern About Common Sense Program Prompts Michigan Officials to Withdraw*, 27 Env't Rep. (BNA) 567, 567 (1996) (quoting a Michigan official as stating that "environmental and environmental justice groups are blocking progress").

209. *See* Dan Beardsley et al., *Improving Environmental Management: What Works, What Doesn't*, ENVIRONMENT, Sept. 1997, at 6, 32; *GOP Staff Says Effort To Reinvent EPA Falls Short, Agency Denounces Findings*, 27 Env't Rep. (BNA) 1151, 1151-52 (1996) (noting a recent report which concluded that the EPA has failed to decrease the number of regulations or to ensure cost-effective implementation); *3M Decides To Drop Out Of Project XL Process After Disagreement Over Performance Guarantees*, 27 Env't Rep. (BNA) 1045, 1046 (1996) (stating that the conditions imposed by the EPA would fail to entrust 3M with the necessary responsibility and accountability and would instead be both restrictive and burdensome).

To a large extent, the reluctance to dive into flexible approaches is understandable given the over two decades of quantitative-based environmental law regulation that has preceded this point. Environmental law is based on a short-term rewards system rewarding only quantitative results—an approach known colloquially as "bean-counting."[210] But when "an organization's focus is exclusively on quantitative results, . . . this management practice tends to 'starve out' creative resources."[211] Because there is no incentive to experiment, the long-term storage of latent learning value, learning that has not yet materialized into tangible performance results, is stultified in a system that focuses on short-term quantitative results. For instance, if one knows that performance under a water pollution regulation is measured each month through a quantitative water quality monitoring test, why would either the regulator or the regulated entities think of pollution control approaches that may have a big payoff, but only after five years?[212]

The disappointing start of the EPA's flexibility initiative thus suggests that nonlinearity in the environmental law system will not come until we are released (that is, release ourselves) from the quantitative-based command-and-control model—not simply able to deviate from it at the margins, but rather able to operate outside its sphere of influence altogether. Problems such as non-point source water pollution and mobile source air pollution cry out for approaches based on experimentation, rapid modification as needed, and variability of performance standards over small and large scales of time and landscape. Environmentalists and industry may demand a system that "locks in" standards

210. *See, e.g.*, John Pendergrass, *States, EPA Talk Past Each Other*, ENVTL. F., Mar.-Apr. 1997, at 8, 8 (stating that the EPA's "measures of the success of its own and states' enforcement programs continue to rely on counting the numbers of actions taken . . . or money spent on environmental projects. EPA relies on these bean-counting measures despite long-standing understanding that the best measures of success relate to environmental conditions"); *Seven Indicators Broaden Measurement of Compliance With Environmental Laws*, 27 Env't Rep. (BNA) 2155, 2155 (1997) (announcing New York's seven new categories for enforcement performance measurement that nonetheless maintain traditional measures of compliance). The EPA has responded to this criticism with a commitment to improve the orientation of performance measurement toward actual environmental conditions. *See* U.S. ENVTL. PROTECTION AGENCY, EPA STRATEGIC PLAN (Draft June 1997) (copy on file with the *Houston Law Review*); U.S. ENVTL. PROTECTION AGENCY, MEASURING THE PERFORMANCE OF EPA'S ENFORCEMENT AND COMPLIANCE ASSURANCE PROGRAM (Draft Sept. 19, 1997) (copy on file with the *Houston Law Review*); Steven A. Herman, *EPA's FY 1997 Enforcement and Compliance Assurance Priorities*, NAT'L ENVTL. ENFORCEMENT J., Feb. 1997, at 3, 6-7.

211. Lumley, *supra* note 146, at 19-20.

212. As Lumley explains, "managing performance solely on the basis of 'real,' quantitatively assessed properties monitored at arbitrary intervals . . . fails to account for latent value resident in creative interference configurations." *Id.* at 19.

uniformly across time and space, narrowing the debate between them to simply address what those standards will be. However, the reality of how best to manage the environment and human behavior demands just the opposite.

4. Diversity: The Pendulum—To Swing or Not to Swing? Disturbance breeds diversity in complex adaptive systems,[213] so what breeds disturbance in the environmental law system? Surely the very nature of the subject matter as a set of complex adaptive systems will push and pull at environmental law, but disturbance also involves the political process of constantly reordering priorities and reorganizing structure. The statutory revolution of environmental law in the 1970s was nothing less than a massive disturbance in this respect, and no one could reasonably argue that the 1970s did not give rise to a wealth of diversity in environmental law.[214] But today the leaders of that charge are found calling for an end to disturbance in the political sense—a form of truce in the continuing debate over the key design questions of environmental law.[215] Complex adaptive systems theory calls for just the opposite.

We have to remember that for the environmental law system to be adaptive, it has to learn; the goal of which is to improve the management capacity of the legal system over its subject matter. Learning in a management context, when the subject matter itself is complex and adaptive, requires sustained creative interference—events that tilt the apple cart—and a willingness to treat the logic of yesterday as "a disposable expedient."[216] Learning of this kind is "not describable in words, not quantitatively measurable,

213. Refer to notes 2-3 *supra* and accompanying text.

214. *See* Ruhl, *Fitness of Law*, *supra* note 15, at 1460-62 (discussing the proliferation of federal environmental law in the 1970s).

215. For example, William Ruckelshaus, twice former EPA Administrator and currently CEO of a major waste disposal company, criticized the Republican takeover of environmental policy in the 104th Congress as

> yet another phase in a dismaying pattern. The anti-environmental push of the nineties is prompted by the pro-environmental excess of the late eighties, which was promoted by the anti-environmental excess of the early eighties, which was prompted by the pro-environmental excess of the seventies, ... So what is wrong with this picture? Aren't such changes in emphasis part of the fabric of democracy? Yes, but in the case of environmental policy, these violent swings have had an unusually devastating—perhaps a *uniquely* devastating—effect on the executive agency entrusted to carry out whatever environmental policy the nation says it wants.

William D. Ruckelshaus, *Stopping the Pendulum*, ENVTL. F., Nov.-Dec. 1995, at 25, 25.

216. *See* Lumley, *supra* note 146, at 15 (relating that traditional linear thinking must be subordinated to the end goal of understanding when addressing complex order in teams).

and not explicitly rememberable."[217] It just happens. But it happens best when we are faced with disturbance events and a diverse set of responsive tools that allow us to adapt, to experiment, or to throw away yesterday's solution when a new problem comes along.[218] When the pendulum of disturbance stops, the breeding ground of diversity runs dry. If we plant a stake in the ground and say that is where environmental law will stick, even if we are supremely pleased with where it is at the moment, we have at that point stopped learning.

5. Self Criticality: Can Environmental Law Change Fast Enough? One would not want to live through the 1970s of environmental law too often—there was an avalanche of law, a punctuation of the "equilibrium" if ever there was one in law.[219] The push toward wholesale deregulation advocated in the 104th Congress[220] would have done the same. Rather than live from avalanche to avalanche, how can environmental law work toward the state of stable disequilibrium inherent in the self-criticality of complex adaptive systems?

To be sure, environmental law has undergone continuous change since the 1970s,[221] but principally with regard to *substance*, not *structure*. The cooperative federalism[222] and command-and-control structure put into place in the 1970s[223] has not moved very much and is still resistant to change.[224] But to take full advantage of its complex adaptive system qualities, the structure of environmental law—more precisely, the answers to

217. *Id.* at 19.

218. *See* KAI N. LEE, COMPASS AND GYROSCOPE 9 (1993) (inferring that adaptive management results in reliable learning and understanding, even when faced with the unexpected, because adaptive management practitioners "correct errors, improve their imperfect understanding, and change action and plans").

219. *See* J.B. Ruhl, *Biodiversity Conservation and the Ever-Expanding Web of Federal Laws Regulating Nonfederal Lands: Time for Something Completely Different?*, 66 U. COLO. L. REV. 555, 578-79 (1995) [hereinafter Ruhl, *Biodiversity Conservation*] (referring to federal environmental regulation that emerged in the 1970s as "a 'web' of substantive constraints and procedural requirements" and chronicling some of the laws that make up this web).

220. Refer to Part III.B.2 *supra* (characterizing the deregulation approach adopted by the 104th Congress as linear and potentially disastrous).

221. Refer to note 215 *supra*.

222. Refer to note 190 *supra* and accompanying text (discussing the concept of cooperative federalism).

223. *See* Emison, *supra* note 14, at 167 (stating that the command-and-control system, which is the state's right under the police power to compel action by establishing and enforcing standards through the administrative and judicial arenas, has been the nation's principle environmental model since the 1970's).

224. *See id.* at 172 (explaining that current environmental debate is the same as in the early 1980's and the result is a "stall-out in the improvement of environmental quality").

the previous four design questions—must *constantly* be reevaluated and be subject to change. This continual reevaluation will ensure that structural change takes place more often, but hopefully with a longer time period between big avalanches. The adaptive system persists in this state of stable disequilibrium, constantly shedding stresses by discarding obsolete structure and making room for new approaches.

B. *Three Legs of a Revolutionized Environmental Law—A Theme for the Revolution*

So what shape for environmental law comes out of the design questions just posed? If our plan is to take advantage of aggregation, flows, nonlinearity, diversity, and self-criticality as I have proposed,[225] how do we do so? Of course, any reader who has been paying attention up until this point will realize that there is no way to provide many details in response. The beauty of the Constitution, for example, is that the Founders resisted the temptation to provide too many details. It is more a collection of guiding principles grouped under several overarching themes. I have laid out what I believe should be the guiding principles of environmental law using the lexicon of complex adaptive systems theory. Now I will offer some suggestions as to the overarching themes of environmental law and policy that appear to be most consistent with those principles.

These themes, like the themes of the Constitution, defy precise definition, but that is no reason to eschew them as unworkable or impractical. Freedom, democracy, justice, and federalism are themes we associate with the Constitution, but they are not defined anywhere in that document. Scholars write books trying to get a handle on what they mean. Congress has passed thousands of laws trying to fulfill their goals. Their meanings are amorphous and changing, but does that mean they are not useful organizing themes for government? Indeed, they define our system and are the factors we use to distinguish among political systems, even though we have no code-like definitions of them.

It is only when we demand delivery of lockstep linear-causal imagery that we must have precisely defined rules by which to operate.[226] In contrast, organizing principles born of "intentional ambiguity" are most useful when we seek the capacity for adaptive

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225. Refer to Part II.A *supra* (reviewing the general properties of complex adaptive systems).

226. *See* Lumley, *supra* note 146, at 16 (proposing that complex order theory requires the employment of a variety of ambiguous terms, which is distracting to linear-causal thinking).

learning.[227] It is only when such organizing themes for a system change that a revolution in learning can take place.[228] This is the depth of change I propose for environmental law. In this respect, I differ markedly with those who advocate reform through incrementalism and linear extrapolation of the present set of organizing principles.[229] The current organizing principles, those established in the federal statutory revolution of the 1970s, do not seem to fit the current agenda of problems.[230] Like coalescing galaxies, however, new themes are emerging in all corners of environmental policy making—themes of policy, process, and performance that I believe form a new model of environmental law and one which more closely fits the complex adaptive system paradigm.

1. Policy: Sustainable Development. There has been no dominant organizing policy principle for the last two decades of environmental law.[231] Rather, environmental policy has been decided on an ad hoc basis worked out through an ongoing struggle between two policy poles: preservationism and resourcism.[232] Contemporary preservationism is guided by a consequentialist philosophy directed toward eliminating human interference with the environment.[233] Resourcism might be thought of as the nihilist opposite of preservationism—eliminating environmental barriers to human pursuits.[234] Because each principle in its polar form marginalizes either environment or humanity, neither is particularly useful in addressing environmental problems of the future, the common characteristic of which is the existence of intricate feedback

227. *See id.* (relaying that intentional ambiguity facilitates the mind's complex ordering concepts).

228. *See id.* at 22 (emphasizing that current linear thinking inhibits an improved understanding that may only be obtained through nonlinear, complex thinking).

229. *See, e.g.*, Samuel P. Hays, *The Future of Environmental Regulation*, 15 J.L. & COM. 549, 584 (1996) (concluding that future environmental regulation will "mov[e] ahead in incremental steps from the well-established directions of the decades since World War II [as a] linear continuation of political forces and strategies" while calling the contrary view "reformist mythology").

230. Refer to Part III.A *supra* (reviewing the command-and-control system).

231. Refer to note 215 *supra*.

232. *See* J. Baird Callicott & Karen Mumford, *Ecological Sustainability as a Conservation Concept*, CONSERVATION BIOLOGY, Feb. 1997, at 32, 34 (identifying "resource conservation" and "wilderness preservation" as philosophies that dominated the first three quarters of the twentieth century).

233. *See id.* at 35 (identifying preservationism as valuing biota for their own sake and accordingly assigning priority to biological conservation over nonconsumptive human uses of the environment).

234. *See id.* at 34 (defining resourcism as valuing nature "only to the extent that is humanly useful").

cycles between the human and environmental conditions.[235] For example, it will do little good to talk of protecting endangered species in highly-populated, poverty-stricken areas where basic daily human survival depends on extraction of water, fuelwood, and other resources from the environment. On the other hand, it will do little good in such areas to fail to address resource protection if the collapse of the resource base only worsens the human condition. By each focusing on only one side of that feedback cycle, preservationism and resourcism are fundamentally reductionist and thus doomed to miss the point more times than not.[236]

A policy principle is needed that transcends the preservationism-resourcism dichotomy to address such complicated problems in an adaptive manner. The theme that is emerging, known as sustainable development,[237] holds much promise in that respect.The literature attempting to define what sustainable development means and how to implement it as a coordinating policy principle is burgeoning.[238] The prevailing definition of sustainable development at the international level comes from the 1987 Brundtland Report of the World Commission on Environment and Development: "[A] process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations."[239]

Further, we have learned from the President's Commission on Sustainable Development what these international ideals mean for the United States:

> A sustainable United States will have a growing economy that provides equitable opportunities for satisfying livelihoods and a safe, healthy, high quality of life for current

235. *See id.* at 38 (indicating that resourcism is "reductive and ignores nonresources" and that "classic preservationism is driven by nonbiological concerns").

236. *See id.* (concluding that resourcism fails to take nonresources into account and that preservationism focuses on nonbiological concerns).

237. *See id.* at 34 (explaining that sustainable development is a relatively recent concept "betrothed to neoclassical economics").

238. *See* WORLD FUTURE SOC'Y, ENVIRONMENTAL ISSUES AND SUSTAINABLE FUTURES (Michael Marien ed., 1996) (abstracting 450 books and identifying 170 periodicals dealing with sustainable development and related topics). Information about international efforts to implement and coordinate sustainable development is available from the United Nations Division for Sustainable Development's home page, <http://www.un.org/dpcsd/dsd.htm> (last visited Sept. 2, 1997).

239. WORLD COMM'N ON ENV'T & DEV., OUR COMMON FUTURE 46 (1987). *See also* AGENDA 21: THE EARTH SUMMIT STRATEGY TO SAVE OUR PLANET 39 (Daniel Sitarz ed., 1994) (declaring that "[a]ltering consumption patterns is one of humanity's greatest challenges in the quest for environmentally sound and sustainable development").

and future generations. Our nation will protect its environment, its natural resource base, and the functions and viability of natural systems on which all life depends.[240]

It is no accident that these definitions eschew alignment with either the preservationism or resourcism orientations—terms such as sustainable *growth* and sustainable *environment* would not have transcended the debate.[241] Sustainable *development*, however, implies that an economy can thrive and meet human needs without necessarily growing in the sense of increased throughput of resources.[242] But it also implies that economic prosperity matters and that resources must be used to maintain social equity.[243] Indeed, many diehard capitalists and environmentalists alike have begun to realize that the best business opportunity of the future is environmental sustainability[244] and that the best environmental protection opportunity of the future is economic sustainability.[245]

Sustainable development, the combination of economic and environmental sustainability, has always been a necessity. Usually, however, the reality of the need to practice sustainable development has only become apparent in advanced cases of localized

240. PRESIDENT'S COUNCIL ON SUSTAINABLE DEVELOPMENT, SUSTAINABLE AMERICA at i (1996) (quoting the Council's Vision Statement).

241. Indeed, one measure of the success of the international and national efforts to define sustainable development has been their ability to balance between the two poles as reflected by the amount of criticism the extremists from both camps have aimed at that balanced approach. *See, e.g.*, Bill Willers, *Sustainable Development: A New World Deception*, 8 CONSERVATION BIOLOGY 1146, 1146-47 (1994) (criticizing the sustainable development model from the preservationist perspective). As soon as sustainable development becomes a reconstituted version of preservationism or resourcism, it has failed.

242. *See* Callicott & Mumford, *supra* note 232, at 34 (referring to sustainable development as a concept that should be thought of as equal to increased efficiency). "Growth implies quantitative physical or material increase; development implies qualitative improvement or at least change . . . . Our planet develops over time without growing. Our economy, a subsystem of the finite and nongrowing earth, must eventually adapt to a similar pattern of development without throughput growth." Robert Goodland, *The Concept of Environmental Sustainability*, 26 ANN. REV. ECOLOGY & SYSTEMATICS 1, 9 (1995).

243. *See* Goodland, *supra* note 242, at 2 (suggesting that general sustainability should be based on all three aspects of sustainability—"environmental, social, and economic"); Fen Osler Hampson & Judith Reppy, *Environmental Change & Social Justice*, ENVIRONMENT, Apr. 1997, at 12, 13 (emphasizing that social sustainability must deal with how to account for the interests of disenfranchised populations, such as indigenous populations, the poor, and unborn generations).

244. *See, e.g.*, Hart, *supra* note 115, at 67 (commenting on the fact that many companies are "going green," which reduces pollution and increases profits simultaneously).

245. *See, e.g.*, Paul Hawken, *Natural Capitalism*, MOTHER JONES, Mar.-Apr. 1997, at 40, 60 (envisioning a resource productivity revolution in the future, promising a more efficient economy and thereby environmental protection).

unsustainable development. Cases of social collapse caused by unsustainable development abound in history.[246] Today's movement to define sustainable development as an explicit policy tool is merely a reflection of the mounting reality that unsustainable development is becoming more likely in more settings, even to the point of being a global possibility. Sustainable development, in other words, must be a deliberate practice in today's world—a guiding principle for all social decisions.

To be sure, whether the prevailing definitions of sustainable development turn out to be more useful than simple bumper sticker slogans such as "think globally, act locally" will depend on the implementation follow-through. However, it should not be a concern that the definitions are open-ended and nonprescriptive. Many of the issues that motivate discussion of sustainable development—such as climate change, depletion of stratospheric ozone, persistent organic pollutants, loss of biodiversity, ocean degradation, and the like—are truly world-wide in scale and require world-wide responses at all levels of organization from international to local.[247] But environmental policy is not unique in that respect, as other social policy issues such as economic prosperity, democracy, political repression, and gender and race discrimination operate globally from top to bottom. Yet we do not demand detailed "definitions" of democracy and justice in order to agree that they are useful concepts that should be expressed as international, national, provincial, and local goals for addressing those social problems. We have no more reason to define sustainable development beyond the broad ideals captured by the Brundtland Commission. That alone, however, is truly a revolutionary development in environmental policy.

246. *See* CLAYTON & RADCLIFFE, *supra* note 14, at 3 (providing "the Old Kingdom of Egypt around 1950 BC, the Sumerians in 1800 BC, the Maya at about 600 AD and of the Polynesians of Easter Island at about 1600 AD" as examples of civilizations that collapsed due to environmental degradation); Linda S. Cordell, *Models and Frameworks for Archaeological Analysis of Resource Stress in the American Southwest, in* EVOLVING COMPLEXITY AND ENVIRONMENTAL RISK IN THE PREHISTORIC SOUTHWEST at 251, 261 (Joseph A. Tainter & Bonnie Bagley Tainter eds., 1996) (relating that cultural environment is closely related to natural environment).

247. A number of commentators have begun to explore how sustainable development translates into local land use and environmental polices. *See, e.g.*, Jon Chandler, *Regional Growth Means Achievable Growth*, NAT. RESOURCES L. INST. NEWS, Summer 1996, at 11, 11 (observing the policies of the city of Portland, Oregon); James Longhurst et al., *Towards Sustainable Airport Development*, 16 THE ENVIRONMENTALIST 197, 197-201 (1996) (applying sustainable development principles to the level of a single airport development); J.B. Ruhl, *Taming the Suburban Amoeba in the Ecosystem Age: Some Do's and Don'ts*, 3 WIDENER SYMP. L.J. __ (forthcoming) (applying sustainable development principles to suburban growth issues) (draft on file with the *Houston Law Review*).

2. Process: Adaptive Management. The process principle for modern environmental law has been the command-and-control model carried out through so-called cooperative federalism.[248] This model has proven to be a tremendously nonadaptive process, as decisions, once made, tend to lock into place. It is unlikely that the policy principle of sustainable development can be given life through the ossified command-and-control regime.

The alternative approach emerging increasingly at many different levels of decision making is known as adaptive management. Adaptive management's strongest champion is Kai Lee, who defines it as applying "the concept of experimentation to the design and implementation of natural-resource and environmental policies."[249] The point is to move decision making out of the laboratory modeling approach and into the field, and to open the process up to continuous change based on a continuous input of information and analysis.[250] The factors Lee describes as requiring this experimentalist approach in environmental policy are straight out of complex adaptive systems theory: "The behavior of natural systems is incompletely understood. Predictions of behavior are accordingly incomplete and often incorrect. These facts do not decrease the value of models, but they do make it clear that ecosystem models are not at all like engineering models of bridges or oil refineries."[251]

Indeed, Lee points out that the behavior of human systems is equally unclear, and, hence, we do not really know how to get to either a sustainable economy or sustainable development.[252] Failure to experiment, in other words, would be folly. Lee's early work applying that approach to the Columbia River ecosystem has led other commentators to propose an even broader agenda of adaptive management in environmental policy,[253] which is beginning to take hold in concrete policy proposals[254] and government programs.[255]

248. Refer to note 190 *supra* and accompanying text (discussing cooperative federalism and the command and control system).

249. LEE, *supra* note 218, at 53.

250. *See* George Frampton, *Ecosystem Management in the Clinton Administration*, 7 DUKE ENVTL. L. & POL'Y F. 39, 45 (1996) (commenting that adaptive management calls for continuous revision and adjustment of plans as conditions change).

251. LEE, *supra* note 218, at 61.

252. *See id.* at 8 (asserting that, in order to achieve an environmentally sustainable economy, we must first learn to understand the relationship between humans and nature and the relationships among people).

253. *See* THE KEYSTONE CTR., THE KEYSTONE NATIONAL POLICY DIALOGUE ON ECOSYSTEM MANAGEMENT 15-21 (1996)

254. *See id.* (advocating adaptive management techniques as the framework for ecosystem management).

255. *See* U.S. FISH & WILDLIFE SERV., U.S. DEP'T OF INTERIOR, & NATIONAL

3. Performance: Biological Diversity. The method of measuring the performance of environmental law thus far has depended heavily on a "bean counter" mentality.[256] We count the number of endangered species, the volume of contaminants, the number of acres preserved, the number of enforcement actions, and so on. While these measures are useful to the command-and-control regime, they do not offer much to the adaptive management approach.

As Lee explains, the adaptive management approach is hungry for information.[257] When applied to the sustainable development policy, therefore, adaptive management requires information regarding economic, social, and environmental sustainability.[258] Measures of economic and social sustainability at international, national, and local levels abound already, although some commentators have argued they must be refined in order more accurately to take into account resource uses and depletions.[259] Where we are sorely lacking, by contrast, is in the field of information regarding environmental sustainability.

The emerging measure of environmental sustainability, known as biological diversity or biodiversity,[260] has galvanized

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MARINE FISHERIES SERV., U.S. DEP'T OF COMMERCE, ENDANGERED SPECIES HABITAT CONSERVATION PLANNING HANDBOOK 3-24 to 3-26 (1996) (advocating the use of adaptive management techniques in permitting under the Endangered Species Act); Frampton, *supra* note 250, at 45-46 (discussing use of adaptive management methods in endangered species protection programs).

256. Refer to notes 197-98 *supra* and accompanying text.

257. *See* LEE, *supra* note 218, at 9 (relating that adaptive management takes special care with information, transforming it into learning).

258. Refer to note 250-55 *supra* and accompanying text.

259. *See, e.g.*, Abramovitz, *supra* note 5, at 112-13; Robert Repetto, *Earth in the Balance Sheet: Incorporating Natural Resources in National Income Accounts*, ENVIRONMENT, Sept. 1992, at 13, 43 (suggesting that national accounting systems change in order to accurately reflect resource capital depletion).

260. *See* WILSON, *supra* note 84, at 393 (defining biodiversity as "[t]he variety of organisms considered at all levels, from genetic variants belonging to the same species through arrays of species to arrays of genera, families, and still higher taxonomic levels"); *see also* U.S. ENVTL. PROTECTION AGENCY, THREATS TO BIOLOGICAL DIVERSITY IN THE UNITED STATES 10 (1990) (regarding biological diversity as "the variety of life on all levels of organization, represented by the number and relative frequencies of items"); *Convention on Biological Diversity*, 31 INT'L LEGAL MATERIALS 818, 823 (1992) (stating that biological diversity is "the variability among living organisms from all sources . . . [which] includes diversity within species, between species, and of ecosystems"). The focus of scientific research geared towards ecosystem-level dynamics has revealed the dramatic impact that habitat loss has had on biodiversity. *See, e.g.*, Edward T. LaRoe, *Biodiversity: A New Challenge*, *in* OUR LIVING RESOURCES 6, 6-7 (Edward T. LaRoe et al. eds., 1995) (discussing the rapidly increasing rate of extinction and the impact it will likely have on the earth); REED F. NOSS ET AL., NATIONAL BIOLOGICAL SERV., U.S. DEP'T OF THE INTERIOR, BIOLOGICAL REP. 28, ENDANGERED ECOSYSTEMS OF THE UNITED STATES 14 (1995) (inferring that the decline in wetlands has contributed to the rise in endangered spe-

both the scientific and policy communities. The relatively new discipline of conservation biology[261] tells us that biodiversity is the building block of conservation policy as the basic measure of ecosystem health.[262] Regardless of whatever debate might exist over the rate of loss of biodiversity, it appears widely accepted that biodiversity provides a strong index of ecological sustainability[263] and that we are generally experiencing more losses than gains globally.[264] Accordingly, programs such as the National Biological Information Infrastructure[265] and the Gap Analysis Program[266] are now used as means of improving environmental

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cies dependent on wetlands); Scott K. Robinson et al., *Regional Forest Fragmentation and the Nesting Success of Migratory Birds*, 267 SCIENCE 1987, 1987 (1995) (noting that habitat fragmentation may have caused the population decline of migrant birds). For a summary of the biodiversity conservation policy formulation initiatives of 18 federal agencies, see generally CONGRESSIONAL RESEARCH SERV., No. 94-339 ENR, ECOSYSTEM MANAGEMENT: FEDERAL AGENCY ACTIVITIES (April 19, 1994).

261. Conservation biology has emerged as a biological sciences discipline largely in the past decade, as traced by its chief literature and research outlet, the journal *Conservation Biology*. *See Goals and Objectives of the Society for Conservation Biology*, 8 CONSERVATION BIOLOGY at i (1994) (stating that the goal of conservation biology is "to help develop the scientific and technical means for the protection, maintenance, and restoration of life on this planet—its species, its ecological and evolutionary processes, and its particular and total environment").

262. *See* Callicott & Mumford, *supra* note 232, at 39 (observing that healthy ecosystems result from biodiversity and ecological integrity and that biological diversity is a major indicator of ecosystem health).

263. *See* Reice, *supra* note 76, at 428-30 (relating that community structure is dependent on the biodiversity in the area).

264. *See* Christopher Flavin, *The Legacy of Rio*, *in* STATE OF THE WORLD 1997, 2, 13-16 (Linda Starke ed., 1997).

265. The National Biological Information Infrastructure ("NBII") began in 1993 as a distinct bureau of the Department of the Interior known as the National Biological Survey. *See* NBII Brochure Homepage <http://www.nbs.gov> (last visited Nov. 16, 1997). The program name later was changed to National Biological Service ("NBS"), and subsequent to that the program was merged into the United States Geological Survey ("USGS") as the Biological Resources Division ("BRD"). *See id.* The NBII is a BRD led initiative. *Id.* The BRD was created by consolidating the biological research, inventory and monitoring, and information transfer programs of seven different Department of the Interior bureaus. *See id.* Today the BRD is a non-regulatory, non-managerial, non-advocacy science agency with over 1800 employees and a $137 million annual budget; its principal function is to maintain the NBII, an evolution of the original NBS concept. *See id.* The goal of the NBII is to develop an "electronic 'federation' of biological data and information sources," and to provide access to such information. *Id.*

266. The Gap Analysis Program ("GAP") refers to a state-based cooperative program using Geographic Information Systems ("GIS") technology to map major indicators of biodiversity over states, along with the existing network of conservation lands. *See* A. Ross Kiester et al., *Conservation Prioritization Using GAP Data*, 10 CONSERVATION BIOLOGY 1332, 1333 (1996). GAP, which is coordinated by the USGS Biological Resources Division, currently is made up of 430 coordinating units in 43 states. *See id.* GAP has become an important component of conservation biology research. *See id.*

decision making by increasing the availability, uniformity, and scope of information regarding biodiversity. The new policy model that has emerged from the combination of those efforts is known as "ecosystem management," which increasingly has become synonymous with adaptive management.[267]

In order to make information about biological diversity most useful to the adaptive management approach, a number of researchers have embarked on an effort to translate biological diversity information into hard data on the value of nature to the goal of sustainable development. This effort goes beyond the familiar mantra that biodiversity is valuable because the cure for cancer could be found in some bug in Brazil. That possibility offers very little in terms of guidance as to which ecosystem to preserve since every ecosystem has roughly an equal chance of housing that proverbial bug.[268] Rather, we are discovering that we can translate nature into its service values, such as the value of wild honeybee pollination to agriculture, of water filtering by wetlands, of carbon cycling by forests, and so on.[269] As Professor James Salzman has posited, these valuations of "nature's services" can be used to create indices of ecosystem sustainability, which, when combined with improved economic and social sustainability indices, can be used the same way Wall Street uses stock performance indices to make adaptive decisions.[270] Hence,

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267. For excellent overviews of the ecosystem management philosophy, including its application through adaptive management techniques, see THE KEYSTONE CTR., *supra* note 253, at 5-22; STEVEN L. YAFFEE ET AL., ECOSYSTEM MANAGEMENT IN THE UNITED STATES 35-38 (1996) (reviewing recommendations for future ecosystem management projects); R. Edward Grumbine, *Reflections on "What is Ecosystem Management?"*, 11 CONSERVATION BIOLOGY 41, 41-42 (1997) (revisiting ecosystem management themes and highlighting the lessons and dilemmas of putting the concept into practice); R. Edward Grumbine, *What Is Ecosystem Management?*, 8 CONSERVATION BIOLOGY 27, 28, 31 (1994) (explaining that ecosystem management is a response to the current biodiversity crisis and identifying adaptive management as a dominant theme of ecosystem management); and Rebecca W. Thomson, *Ecosystem Management: Great Idea, But What Is It, Will It Work, and Who Will Pay?*, NAT. RESOURCES & ENV'T, Winter 1995, at 42, 70-72 (pointing out the difficulties of the ecosystem management approach, including the barriers presented by adaptive management—"continuous monitoring and assessment *and* the modification of management choices on the basis of new information").

268. *See Conservation Strategies*, ENVIRONMENT, May 1997, at 22, 22 (suggesting that the number of species that could lead to a valuable product is so large that the probability that any one species will do so is very small).

269. *See* CENTER FOR RESOURCES ECONS., NATURE'S SERVICES 177-254 (Gretchen C. Daily ed., 1997) (providing a comprehensive review from various authors of what is already known about ecosystem services, how the information can be transformed into valuation estimations that can be used to better understand human impact on ecosystems, and the monumental research agenda that will need to be implemented to create a sufficient information source upon which to base reliable decisions).

270. *See* James Salzman, *Valuing Ecosystem Services*, 24 ECOLOGY L.Q. __ (forthcoming) (calling for integration of "robust, quantified indicators of ecosystem

the new measures of environmental health found in the concepts of biodiversity and valuation of nature's services converge neatly with notions of adaptive management and sustainable development.

V. CONCLUSION—WHOSE VIEW OF ENVIRONMENTAL LAW WILL BE IRRELEVANT IN TWENTY YEARS?

Is it an accident that sustainable development, adaptive management, and biodiversity were unheard of in the environmental policy debates of twenty years ago and today are the staple of conferences, symposia, and journals? I think not. Rather, the evolution of environmental law has led us to this point precisely because these three concepts are related and because they are consistent with the vision of law as a complex adaptive system. Thus, Gerald Emison's exploration of complex systems as a model for environmental law reaches a similar set of conclusions as to the direction of reform through which he advocates a system designed to: (1) get accurate, detailed information; (2) challenge sources to achieve measurable goals for sustained progress; (3) use all parts of the environmental management system; (4) use incentives to promote responsible behavior; (5) pay close attention to implementation; (6) make innovation a priority; and (7) emphasize flexibility.[271] I posit that the legal apparatus, for turning those approaches into reality, is "gelling" through the trio of loosely defined organizing principles known as sustainable development, adaptive management, and biodiversity, and that the critical mass behind that transformation has reached the point at which the process of change will not be stopped.

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services" into a new "ecosystem jurisprudence" to improve regulatory decision making, provide information relevant to market-based approaches, and assist in reaching conclusions as to causality) (draft on file with the *Houston Law Review*). This approach is being actively pursued by international and national organizations. *See, e.g.*, United Nations Department for Policy Coordination and Sustainable Development, *From Theory to Practice: Indicators of Sustainable Development* (visited Oct. 3, 1997) <http://www.un.ogr/dpcsd/dsd/indi6.htm> (discussing the Work Programme on Indicators of Sustainable Development of the United Nation Commission on Sustainable Development); WORLD RESOURCES INST., ENVIRONMENTAL INDICATORS 11-17 (1995).

271. *See* Emison, *supra* note 14, at 187-92; *see also* Kenneth L. Rosenbaum, *The Challenge of Achieving Sustainable Development Through Law*, 27 Envtl. L. Rep. (Envtl. L. Inst.) 10455 (1997). Suggesting the same criticism of reductionist environmental policies that I make, Rosenbaum observes that "the complexity of the world leads the law to split problems into pieces, and the splits inevitably cause complications." *Id.* at 10457. He advocates working toward sustainable development as the goal, through increased reliance on feedback and flexibility. *See id.* at 10460-61.

The real question, of course, is who will win the debate over how to shape the legal framework within which those three themes either flourish or dissipate. I make no bones about it: my view of the environmental law of the future is vastly different from the one portrayed by the "incrementalists."[272] The problems of the next two decades—population growth, climate change, malnutrition, disease, and so on—no longer seem to be incremental, linear extensions of the problems of the past. Why should we expect that incremental changes in law will address those problems adequately? Does it make any sense, for example, to think of overlaying the Endangered Species Act on China or Ethiopia? How much more reasonable is it to think we can accomplish change domestically on behalf of endangered species through federal fiat? Incrementalism eventually will become irrelevant simply because it will prove decreasingly useful in answering those and similar questions.

The primary objection I expect to hear to my view of environmental law is that it does not allow us today to produce a script of objective, uniform, predictable, and easily enforceable standards to be applied for the foreseeable future. It is not a "litigable" body of law to apply. Precisely! If adaptability means we have less law to apply, then let us have less law to apply. If adaptability means that planning horizons for business and government shrink, then let them shrink. The whole point of applying complex adaptive systems analysis to law is to demonstrate that efforts to cling to a highly predictable, stable, rule-habituated system of law undermine the adaptability of law to its changing subject matter. The framework for carrying out sustainable development necessarily must be loose, relying heavily on inclusive negotiation forums operating at all levels of government and less on centralized fiat. Our efforts should be directed toward creating the legal frameworks within which those processes can flourish.[273] The point is to design environmental

272. Refer to Part III.B.1 *supra* (referring to current environmental policy as incremental).

273. For an example of what I have in mind, see Ruhl, *Biodiversity Conservation*, *supra* note 219, at 661-71. Briefly, I propose a legal regime for biodiversity conservation which would allow state and local governments to identify "biological resource zones." *See id.* at 663-65. Once a zone is identified, the nonfederal entities would submit land use and environmental management plans for the zone to the federal government, which would evaluate whether the plan will lead to *overall* biodiversity conservation and environmental quality within the zone equal to or greater than that which would be achieved under the other federal environmental laws, such as the ESA and Clean Water Act. *See id.* at 669-70. If that finding is made, the nonfederal entities would administer the land use plan within the zone, in return for which the operation of the other federal laws would be suspended. *See id.* at 670-71. The plan would be reevaluated periodically and adjusted as needed.

law to protect the environment, not to protect the law and lawyers.

The last three decades of environmental law, the command-and-control era of so-called "cooperative federalism," made great strides by taking shortcuts around the reality that the subject matter of environmental law is a set of complex adaptive systems.[274] But shortcuts can only work for so long. We find ourselves staring into the reality of environmental policy as never before, asking questions like: "Will we be able to sustain the planet, and for how long?" There are no simple answers to those questions; rather, we will have to resign ourselves to having to answer and reanswer those questions over and over, taking risks along the way through experimentation, though with the benefit of as much information as we can collect. The process will be a mess! It will not be easy, or inexpensive, or something we can leave to only a few "experts" in centralized administrative agencies to carry out. We will *never* be able to rest from the task, but if we are right in asking questions of that magnitude, then we should demand nothing less of ourselves.

The single greatest obstacle to getting there, to even beginning to talk about how to get there, is trust, specifically overcoming the complete lack of trust that personifies today's environmental law and policy.[275] When I hear someone say they need "litigable standards" and "verifiable compliance," what I really hear is that they do not trust the other party with whom they are dealing. As Francis Fukuyama has observed, "[P]eople who do not trust one another will end up cooperating only under a system of formal rules and regulations, which have to be negotiated, agreed to, litigated, and enforced, sometimes by coercive means."[276] To think of environmental law as a complex adaptive system—to deliberately reshape environmental law around the new organizing principles of sustainable development, adaptive management, and biodiversity—we will need to trust one another.[277] That will prove hard for many who have lived through the grenade throwing days of the past three decades. But when you stop and consider the very imminent future of a planet with over ten billion people on it, do we have any choice?

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274. Refer to Part IV.A.1 *supra* and accompanying text (reviewing the command and control structure and cooperative federalism).

275. *See* Ruckelshaus, *supra* note 215, at 27-28 (commenting on the steady erosion of trust in all institutions, at the epicenter of which is the EPA).

276. FRANCIS FUKUYAMA, TRUST: THE SOCIAL VIRTUES AND THE CREATION OF PROSPERITY 27 (1995).

277 In their prescription for improving environmental law, which focuses on many of the themes raised here, Dan Beardsley and colleagues call for installing a "process for implementing new initiatives that features open exchange of information, sensible levels of stakeholder participation, and, if possible, trust." Beardsley, *supra* note 209, at 8.