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# SOME PRINCIPLES OF CONSERVATION BIOLOGY, AS THEY APPLY TO ENVIRONMENTAL LAW

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## Introduction

Conservation is not as simple today as in the past. One hundred years ago it seemed that if we could just stop the plume hunters from shooting egrets to decorate ladies' hats, and if we could only save a few areas of spectacular scenery in national parks, we were doing well. Somewhat later it became apparent that we had to protect many kinds of habitats (wetlands, grasslands, deserts, forests of all kinds) to save wildlife. To that end, we established a series of reserves including national wildlife refuges, research natural areas, state nature preserves, and private sanctuaries managed by groups such as The Nature Conservancy and National Audubon Society. The tacit assumption was that these little enclaves of nature would persist forever in the stable "climax" condition in which we found them.

As ecology, genetics, and other biological sciences matured, they slowly began to have more influence on conservation philosophy, and in the last two decades they have begun to inform conservation practice. But as the influence of scientists on environmental policy increased, so did doubts about our ability to comprehend nature.

Ecological science has undergone significant changes in recent years. Among the new paradigms in ecology, none is more revolutionary than the idea that nature is not delicately balanced in equilibrium, but rather is dynamic, often unpredictable, and perhaps even chaotic.[2] It follows that classical preservationist approaches to conservation, to the extent that they attempt to hold nature static, do not reflect realities of nature. A related idea is that ecological phenomena operate across vast landscapes, and that parks and other areas set aside for their natural qualities are inevitably buffeted by exotic species invasions, uncontrolled human activities, disruptions of hydrology, and other cross-boundary effects.

Nature cannot be expected to manage itself and maintain all of its components in a world where natural processes have been dramatically altered. Even the largest wild areas on earth are changing inexorably due to natural forces and are now being affected by long-distance transport of pollutants, thinning of the ozone layer, and probably global warming. As undeveloped areas become smaller and more isolated from one another, they are affected more strongly by their surroundings and are less likely to maintain their biodiversity. Thus, the new ecological paradigm, described in Professor Meyer's article, suggests that reserves are not enough. If we are really interested in maintaining ecological processes and the services they provide to human society, then conservation must be extended to entire landscapes or regional ecosystems. Almost all conservationists agree that some sort of "ecosystem management" is necessary to maintain biodiversity and ecological integrity in today's world.[3] In this Article, I offer some principles and concepts from conservation biology that might help us manage ecosystems in a prudent and responsible fashion. These principles also have implications for environmental law. But first I will examine briefly the issue of values.

## I. Conservation Biology and Values

The emergence of conservation biology as a distinct discipline in the late 1970s and its flowering in the mid-80s with the founding of the Society for Conservation Biology can be traced to the increasing interest of ecologists, geneticists, and other "basic" biological scientists in conservation problems and the dissatisfaction of these scientists with wildlife management, forestry, fisheries, and other traditional natural resource disciplines. The resource disciplines were concerned with mostly utilitarian ends and focused on a narrow range of the biological spectrum, chiefly game birds and mammals, edible fish, commercial trees, and livestock forage. Although the resource disciplines had already begun to broaden in the 1970s with more attention to "nongame" and endangered species, the broadening was not great or fast enough for conservationists interested in biodiversity, the total variety of life on earth. Moreover, it was quickly recognized that because conservation problems are inherently transdisciplinary, conservation biology must involve not only biologists, but also geographers, sociologists, economists, philosophers, lawyers, political scientists, educators, artists, and other professionals.

A distinguishing feature of conservation biology is that it is mission oriented.[4] Underlying any mission is a set of values. Philosophers of science now recognize that no science is value free, despite all we were taught in school about the strict objectivity of the scientific method. Conservation biology is more value-laden than most sciences because it is not concerned with knowledge for its own sake but rather is directed toward particular goals. Maintaining biodiversity is an unquestioned goal of conservation biologists. Sometimes an exercise in conservation biology is highly specific in its mission. For example, we might be interested in maintaining a viable population of Furbish's lousewort, defined perhaps as having a 99% chance of surviving for 500 years. Alternately, we might propose goals that are broad and ambitious. For instance, the goals of The Wildlands Project, an effort in which I and many other conservation biologists and activists are involved, are to (1) represent all types of ecosystems across their natural range of variation in protected areas; (2) maintain viable populations of all native species in each region, with most attention to species especially sensitive to human activities; (3) sustain the full suite of ecological and evolutionary processes; and (4) create a conservation system that is adaptable to a changing environment.[5]

Underlying the goals and objectives of conservation biology, whether general or specific, is the fundamental value assumption that biodiversity is good and ought to be preserved. I emphasize this point because many detractors of conservation do not seem to share this assumption. Getting to the heart of an environmental conflict often requires that we examine differences among people in their basic value systems. As an example, the idea that biodiversity is good and that species have inherent value is implicit in the U.S. Endangered Species Act ("ESA") and to some extent in the National Forest Management Act and other pieces of environmental legislation.[6] People who seek to weaken these laws question the intrinsic value of species and attempt to put the burden of proof on environmentalists to demonstrate that a species provides direct benefits to human society and therefore warrants protection.

In practice, if not in intent, the burden of proof in the ESA and National Environmental Policy Act ("NEPA") is already on those who wish to protect the species or the environment. In NEPA decisions, a dam, highway, or other project is considered benign unless an environmental impact statement demonstrates convincingly otherwise.[7] In listing decisions under the ESA, the burden is on the citizens who petition to list a species to present data on threat to the species that the Fish and Wildlife Service considers "substantial."[8]

Putting the burden of proof on those who would protect the environment is consistent with conventional practice in scientific research, where the statistical significance of a result corresponds to how low the chance is of committing a Type I error. A Type I error occurs when one rejects a true null hypothesis and claims an effect (say, of a real estate development or a timber sale) when none really exists. Conventional statistical analyses are designed to minimize the probability of Type I errors, but in so doing they increase the chance of committing a Type II error, failing to reject a false null hypothesis or claiming no effect when one actually exists. The scientific preference for committing Type II rather than Type I errors is congruent with the "innocent until proven guilty" standard in criminal law, as opposed to cases in torts.[9] In criminal law, it is assumed that acquitting a guilty person is not as bad as convicting an innocent person. However, the innocent until proven guilty standard sometimes imposes unacceptable risks on society. Several scientists have pointed out that Type II errors are more dangerous than Type I errors in applied sciences such as medicine, environmental engineering, and conservation biology because they can result in irreversible damage,[10] for example death of a patient due to side effects of a drug,[11] death and sickness of many innocent people in the cases of Bhopal and Chernobyl,[12] or extinction of species.[13] As exemplified by Taylor and Gerrodette:

> Consider a medical test that determines whether a patient has some deadly disease. Physicians are properly less concerned with a false positive (concluding that the patient has the disease when she does not) than with a false negative (concluding that the patient does not have the disease when she does). Conservation biologists deal with the health of species and ecosystems and should be similarly concerned with false negatives.[14]

The philosophy underlying conservation biology and other applied sciences is one of prudence: in the face of uncertainty, applied scientists have an ethical obligation to risk erring on the side of preservation. Thus, anyone attempting to modify a natural environment and put biodiversity at risk is guilty until proven innocent. This shift in burden of proof is consistent with the precautionary principle, which is gaining increased support in many professions. A precedent for this shift can be found in the U.S. Food and Drug Administration's requirement that the drug industry prove that a drug is not harmful before it is licensed. Belsky recognized that shifting the burden of proof is a major challenge for environmental law.[15] Legal scholars have their work cut out for them here: when the burden of proof is shifted from conservationists to developers, this poses serious questions about the enjoyment of private property rights, "taking" of property, and just compensation.

## II. Principles of Conservation Biology

In the remainder of this Article I will review what I recognize as some emerging principles of conservation biology. Like ecology, conservation biology has so far been largely a science of case studies. Whatever generalities exist, like "everything is connected to everything else," seem trite. But despite the anecdotal nature of much of our knowledge in conservation biology, some principles or empirical generalizations are becoming clear. These principles will hopefully be useful to policy makers, legal scholars, land-use planners, land managers, and conservationists in general, and they can be adapted to scales ranging from local land-use plans to global strategies. I begin with some general principles and then move to specific tasks such as reserve design and ecosystem management. Although any principle is a generalization and will have exceptions, taken together these principles provide a robust basis for conservation planning.

### A. General Principles

The general principles of conservation biology emerge from an appreciation of the complexity of nature, and an understanding that we will never know precisely how nature works. Thus, we had better be as cautious and gentle as possible in our manipulations.

*"Ecosystems are not only more complex than we think, but more complex than we* can *think."*[16] This quote from ecologist Frank Egler was probably based on a 1927 statement by evolutionary biologist J.B.S. Haldane, who said "[m]y suspicion is that the universe is not only queerer than we suppose, but queerer than we *can* suppose."[17] In any case, the proper response to this situation is humility. Humility demands that we prefer erring on the side of preservation to erring on the side of development. Thus, humility demands a shift in burden of proof as discussed earlier.

*The less data or more uncertainty involved, the more conservative a conservation plan must be.* Some non-trivial level of uncertainty accompanies all planning decisions. When information on species locations, population sizes and trends, interspecific interactions, responses to disturbance, and other factors is scarce or questionable, the best interim strategy is one that minimizes development and other human disturbance during the time needed to gather the necessary biological information. For example, when we discovered that not nearly enough data were available for construction of a long-term conservation plan, the Scientific Review Panel for the coastal sage scrub in southern California called for an interim plan involving not more than five percent loss of habitat in each planning subregion during a period of three to six years over which field inventories and research will be conducted. Furthermore, if the plan is implemented as intended, habitat losses will be restricted to patches of low to moderate conservation value such as small sites lacking rare species and surrounded by development.

*Natural is not an absolute, but a relative concept.* Because human impacts penetrate all boundaries, no purely natural areas exist anywhere in the world today. Yet few would disagree that a remnant of virgin forest or tallgrass prairie is more natural than a clearcut or a shopping mall.

*Conservation biology is highly value-laden.* No science is value-free, but values and ethics play a more prominent role in applied, mission-oriented sciences like conservation biology than in basic research. The greatest objectivity follows from stating biases, values, interests, predilections, and goals straightforwardly. Such openness may not seem appropriate in a courtroom, where the assumption seems to be that science is only concerned with facts, but is entirely consistent with the oath of honesty.

*Conservation must be goal-directed.* Explicit (though not necessarily quantitative) goals are better than vague goals, and ambitious goals are usually preferable to weak goals. Without stated goals, conservation programs flounder. In an apparent effort to appear reasonable, some conservationists begin their bargaining with goals that are already highly compromised. Because few goals are ever fully attained, starting with a compromise may mean ending up with nothing.

*In order to be comprehensive, biodiversity conservation must be concerned with multiple levels of biological organization and many different spatial and temporal scales.* There is no one best scale or level of organization for conservation research or action. The trick is finding the best scale for solving each specific problem, then integrating across scales for the overall conservation strategy.

*Conservation biology is interdisciplinary, but biology must determine the bottom line.* Human cultural systems are far more adaptable than biological systems. Thus, although sociological and economic concerns must enter into any conservation planning exercise, the vital needs of nonhuman species must not be compromised. Furthermore, because a healthy economy ultimately depends on a healthy ecosystem, human actions that are not compatible with the integrity of the ecosystem should not be permitted.

## B. Principles of Reserve Design and Management for Target Species

Although ecosystem management is the buzzword of the day, management of individual species on a population or metapopulation level remains a necessary part of any conservation strategy. Without individual attention, many species that have declined due to human activity are likely to become extinct in the near future. Besides, we know much more about managing species than managing ecosystems. The Interagency Scientific Committee that developed a conservation strategy for the northern spotted owl offered five general principles for reserve design that they characterized as "widely accepted" within the community of conservation biologists.[18] Few scientists have disagreed with their bold statement. I paraphrase these five reserve design principles below, then add several of my own that apply to species especially sensitive to human activity.

*Species well distributed across their native range are less susceptible to extinction than species confined to small portions of their range.*[19] The idea here is that a widely distributed species will be unlikely to experience a catastrophe, disturbance, or other negative influence across its entire range at once. For instance, a severe drought may dry up the breeding ponds used by a species of salamander for several years in a row across two or three states. If that salamander occurs nowhere else, it may become extinct. However, if the salamander is distributed broadly, at least some areas within its range are likely to contain breeding ponds that do not dry out completely. From those refugia, the species can slowly recolonize areas where it had been eliminated. As an extreme example, a plant species confined to the slope of a single volcano might be wiped out by one eruption. Keeping species well distributed is therefore a sensible conservation goal and corresponds to the well-accepted "multiplicity" principle, where it is preferable to have many reserves rather than few.[20] The provision of the Endangered Species Act that allows for listing of local populations, even when the species as a whole is not threatened, is consistent with this principle.[21]

*Large blocks of habitat, containing large populations of a target species, are superior to small blocks of habitat containing small populations.*[22] The principle of "bigness" is another of the universally accepted generalizations of conservation biology.[23] All else being equal, large populations are less vulnerable than small populations to extinction. A larger block of suitable habitat will usually contain a larger population. In line with the preceding principle, large blocks of habitat are also less likely to experience a disturbance throughout their area. Thus, refugia and recolonization sources are more likely to occur in large blocks of habitat than in small blocks, thus enhancing population persistence.[24]

*Blocks of habitat close together are better than blocks far apart.*[25] Many organisms are capable of crossing narrow swaths of unsuitable habitat, such as a trail, a narrow road, or a vacant lot; far fewer are able to successfully traverse a six-lane highway or the City of Chicago. In the absence of impenetrable barriers, habitat blocks that are close together will experience more interchange of individuals of a target species than will blocks far apart. If enough interchange occurs between habitat blocks, they are functionally united into a larger population that is less vulnerable to extinction for any number of reasons.[26]

*Habitat in continuous blocks is better than fragmented habitat.*[27] This rule follows logically from the previous two but also brings in some new considerations. Fragmentation involves a reduction in size and an increase in isolation of habitats. The theory of island biogeography predicts that either of these processes will lead to lower species richness due to decreased immigration rates (in the case of isolation) and increased extinction rates (in the case of small size).[28] Thus, a small island far from the mainland is predicted to have the lowest species richness. Looking at a single target species, as is now the fashion in fragmentation studies, a small and isolated habitat patch is expected to have a smaller population and less opportunity for demographic or genetic "rescue" from surrounding populations.[29] In metapopulation theory, an unoccupied patch of suitable habitat isolated by fragmentation is less likely to be colonized or recolonized by the target species.[30] If enough connections between suitable habitat patches are severed, the metapopulation as a whole is destablized and less likely to persist.

But fragmentation involves more than population effects for single species. Effects at community, ecosystem,[31] and landscape levels are also well documented.[32] Briefly, problems at these higher levels include abiotic and biotic edge effects that reduce the area of secure interior habitat in small habitat patches and often lead to proliferation of weedy species; increased human trespass and disturbance of sensitive habitats and species; and disruption of natural disturbance regimes, hydrology, and other natural processes. The end result of fragmentation is often a landscape that has lost sensitive native species and is dominated by exotics and other weeds. Although species richness at the local or landscape scale is often higher after fragmentation than in the undeveloped condition, this richness is misleading because it is accompanied by a homogenization of floras and faunas at a broader scale and by a net loss of sensitive species; the global consequence is biotic impoverishment.

*Interconnected blocks of habitat are better than isolated blocks.* Connectivity (the opposite of fragmentation) has become one of the best accepted principles of conservation planning. Despite continuing arguments over benefits versus costs of particular corridor designs,[33] few conservation biologists would disagree that habitats functionally connected by natural movements of organisms are less subject to extinctions than habitats artificially isolated by human activity. It is also probable that corridors or linkages will function better when habitat within them resembles that preferred by target species. For example, although we do not know exactly what types of habitats the species associated with old-growth forests will travel through, old forests are likely to provide better linkages than fresh clearcuts.

*Blocks of habitat that are roadless or otherwise inaccessible to humans are better than roaded and accessible habitat blocks.* Roads and other providers of human access often lead to high mortality rates for large carnivores, furbearers, desert tortoises, commercially valuable plants such as cacti, and other species exploited or persecuted by people. Although the ultimate solution to these problems must involve education and change in human values and behavior, the immediate need is to restrict access to habitats of sensitive species. For example, land managing agencies often have policies (which may or may not be enforced) calling for road densities not exceeding 0.5 miles per square mile in wolf or grizzly bear habitat. Roads also cause other problems. Roadkill is a primary source of mortality for many species in regions with heavy traffic; dirt roads contribute sediments to streams; and roads are barriers to movement of some small vertebrates and invertebrates. For these and other reasons,[34] roadless areas should be protected, roads should be closed whenever possible, and busy roads should be equipped with underpasses or other wildlife movement passages.

*"[C]onservation strategy should not treat all species as equal but must focus on species and habitats threatened by human activities."*[35] This statement from Jared Diamond seems logical enough, but it is amazing how much time and money has been spent studying and managing species that do not really require human assistance (e.g., white-tailed deer). Similarly, high species diversity in clearcuts and other human-disturbed habitats has been used to justify intensive forestry and other forms of manipulative management, even though the species that thrive in such habitats are mostly opportunistic weeds. The most appropriate target species for conservation are generally those most sensitive to human disturbance.

*Populations that fluctuate widely are more likely to go extinct than populations that are more stable over time.* Mean population size is sometimes a poor indicator of vulnerability. A population with a relatively large mean size but high variance may be more likely to go extinct than a smaller but more stable population.[36] Large-bodied animal species, although more vulnerable to many specific threats, generally fluctuate less and therefore can probably be viable with smaller populations.

*Disjunct or peripheral populations of species are more likely to be genetically impoverished but also genetically distinct than are central populations.* This well-documented pattern is a direct consequence of reduced gene flow to isolated or marginal populations. The pattern presents a dilemma because populations with lower heterozygosity are likely to be less adaptable to future environmental change[37] and therefore might be seen as less important to conserve. Marginal populations are also likely to be in suboptimal habitat. Thus, conservation at the species level may be more effective when directed to the central portion of each species' range. On the other hand, disjunct or peripheral populations are likely to have diverged genetically from central populations due to genetic drift, adaptation to local environments, or both. Directional selective pressures can be expected to be intense for these populations. If we are concerned with maintaining opportunities for speciation (future biodiversity) then conservation of peripheral and disjunct populations is critical. Again, the provision of the Endangered Species Act that allows for listing of distinct populations, even when the species as a whole is not threatened, makes biological sense. Conservation of species across their native ranges is the optimal strategy.

## C. Ecosystem Management

The idea that we can manage ecosystems is arrogant and misleading. However, management based on some understanding of ecosystems and aimed at protecting whole communities or habitat mosaics is certainly sensible. Most of the principles stated above for target species also apply to ecosystem management, because maintaining the integrity of an ecosystem requires that the most sensitive species within that ecosystem remain viable. However, management at the ecosystem level requires some rules of its own.

*Maintaining viable ecosystems is usually more efficient, economical, and effective than a species-by-species approach.* Although, as noted earlier, many sensitive species require individual attention in order to avoid extinction, focusing on every species individually is impossible. There are likely to be thousands of species inhabiting any given region, if we include microbes, soil invertebrates, and other poorly known groups. The "coarse filter" approach[38] of representing all types of habitats and communities in areas managed for their natural values is probably the most inclusive of all conservation strategies. The goal of the Gap Analysis project of the National Biological Survey is to evaluate how well native vegetation types and associated species are represented in protected areas.[39]

*Biodiversity is not distributed randomly or uniformly across the landscape. In establishing protection priorities, focus on "hot spots."* Hot spots are areas of concentrated conservation value, such as centers of endemism or areas of high species richness. Hot spots can be recognized at many spatial scales. For example, globally, the humid tropics stand out as hot spots of species richness, with the greatest diversity for most taxa in Central and South America.[40] But within an area such as the Amazon Basin, biologists have identified hot spots of endemism. Some kinds of organisms, such as coniferous trees, are most diverse in North America. Looking more closely, the greatest diversity of conifers appears to be the seventeen species in the Russian Peak area of northern California.[41] Every landscape has areas of concentrated biodiversity. Map overlays that display multiple conservation criteria can show the locations of these hot spots.

*Ecosystem boundaries should be determined by reference to ecology, not politics.* Ecosystems do not respect property and jurisdictional lines. Ecologists often say that the boundaries of all ecosystems (even the biosphere) are open, exchanging energy and materials with other systems. But of course boundaries are not entirely arbitrary. Topography, geology, soils, and other factors often create discontinuities on the landscape. Ecosystems can be delimited by vegetation, watersheds, or physiography, all of which are hierarchically organized but mappable. Boundaries defined on the basis of ecological criteria are more useful for conservation planning than those defined by conventional political or administrative jurisdiction. The scale and boundaries of the ecosystem should correspond to the management problems at hand. A comprehensive conservation strategy must consider multiple scales.

*Because conservation value varies across a regional landscape, zoning is a useful approach to land-use planning and reserve network design.* Some advocates of ecosystem management favor a "landscape without lines" approach, where human activities are spread throughout a landscape. This approach is not likely to offer sufficient protection to hot spots and areas especially sensitive to human disturbances. A concentric zoning model with protection increasing inward and intensity of human use increasing outward is recommended.[42]

*Ecosystem health and integrity depend on the maintenance of ecological processes.* Flow of energy and cycling of nutrients are fundamental processes of all ecosystems. Photosynthesis, herbivory, predation, disease, decomposition, competition, cooperation, disturbance, succession, erosion, deposition, and other biotic and abiotic processes assure that energy keeps flowing and nutrients keep cycling. Disruption of the characteristic processes of any ecosystem will likely lead to biotic impoverishment. Although even grossly impoverished ecosystems (for instance, an abandoned strip mine or sewage lagoon) continue to function, they cannot be said to have integrity.

*Human disturbances that mimic or simulate natural disturbances are less likely to threaten species than are disturbances radically different from the natural regime.* Species have evolved along with disturbances. Natural selection has provided species with ways to escape, tolerate, or exploit natural disturbances, so that life histories of species are often closely tied to a specific disturbance regime. For example, longleaf pine (*Pinus palustris*) depends on frequent, low-intensity fires to prepare a seedbed of exposed mineral soil and to drive out competing hardwoods. If fires are suppressed for more than several years, hardwoods invade the site and eventually dominate. Any human-induced change in the type, size, frequency, intensity, or seasonality of disturbance can be expected to affect biodiversity. Logging, livestock grazing, and other management practices will be less disruptive when they simulate or mimic natural disturbances. Exactly how closely they must resemble the natural regime to avoid biotic impoverishment is a question unanswered for any ecosystem.

*Ecosystem management requires cooperation among agencies and landowners and coordination of inventory, research, monitoring, and management activities.* Because political and landownership boundaries do not conform to ecological boundaries, agencies and landowners will need to cooperate in order to manage resources and conserve biodiversity effectively. Both within and among agencies, the usually separate functions of biological inventory, research, monitoring, and management should be united into one holistic scheme.

*Management must be adaptive.* Much land management in the past has been trial and error, with errors often not recognized until long after damage was done. Even then, destructive practices often continued because no rigorous studies linked degradation of habitats to specific management practices. Recognizing that every land management practice is an experiment with an uncertain outcome, research and monitoring should be coordinated to test hypotheses about the effects of management treatments on biodiversity and ecological integrity.[43] The information gained from these experiments should be used to adjust management in a desirable direction.

*Natural areas have a critical role to play as benchmarks or control areas for management experiments.* This value was recognized by Aldo Leopold, who pointed out that wilderness provides a "base-datum of normality" for a "science of land health."[44] Scientists shudder to think of experiments without controls, but this is the case for much land management today. Existing natural areas are imperfect baselines for many reasons, but they are the best we have. Ecosystem management, because it is essentially experimental and adaptive, requires natural areas as controls. Unfortunately, many of the proponents of ecosystem management today propose it as an alternative to protected areas, rather than as a necessary complement.

## III. Translating Principles into Action

The emerging principles of conservation biology I have outlined here are not laws. The pathways of natural processes are not entirely predictable. The probabilistic character of all natural phenomena and all statements about nature is not congruent with a legal system that demands certainty. The apparent inability of many people (including lawyers, judges, legislators, and journalists) to appreciate the inherent uncertainty in science is a primary reason why many scientists feel uncomfortable in the courtroom, testifying at congressional hearings, or being involved in public debates of any kind. We might think wishfully that science is becoming more certain over time and that eventually our probabilistic statements about nature can be replaced by firm declarations of fact. How many board feet of timber can we cut each year in the Pacific Northwest without driving the northern spotted owl to extinction? How much coastal sage scrub must we protect, and in what size pieces, to save the California gnatcatcher? Precisely how much water and at what times of year must be delivered to the Everglades in order to keep the ecosystem healthy? Scientists can provide estimates in response to each of these questions, but the estimates are vague and highly uncertain. Surely these estimates will narrow as we learn more, or will they? In ecology and conservation biology, the more we learn, the more we recognize our profound ignorance. Statements in ecology textbooks written twenty or thirty years ago are much more confident than those made today. Today we recognize that non-linear dynamics are the way of nature; therefore extrapolation from past trends or current conditions is hazardous. Ecosystems are always changing and the changes are often unpredictable. Does this mean that we have no standards by which to judge the efficacy of conservation measures or suitability of management practices? Not at all. Although the new paradigm in ecology emphasizes change and non-equilibrium conditions rather than balance or stability, it does not imply that all changes are desirable. As stated by Botkin:

> [T]o accept certain kinds of change is not to accept all kinds of change. Moreover, we must focus our attention on the rates at which changes occur, understanding that certain rates of change are natural, desirable, and acceptable, while others are not. As long as we refuse to admit that any change is natural, we cannot make this distinction and deal with its implications.[45]

## Conclusion

The principles of conservation biology proposed in this Article should be robust in a changing environment. In fact, most of these principles assume a changing and unpredictable environment. The challenge ahead is implementing these principles to specific conservation challenges, knowing that few of the people making the ultimate decisions have anything but a rudimentary understanding of nature. Those legal scholars, lawyers, and policy-makers who do appreciate these principles should be in the forefront of efforts to apply them to real-world conservation, while along the way educating their colleagues.

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Footnote: 2

Daniel B. Botkin, Discordant Harmonies: A New Ecology for the Twenty-first Century 6-13 (1990); *see* Steward T.A. Pickett et al., *The New Paradigm in Ecology: Implications for Conservation Biology Above the Species Level*, *in* Conservation Biology: The Theory and Practice of Nature Conservation Preservation and Management 65, 70-74 (Peggy L. Fiedler & Subodh K. Jain eds., 1992).

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Footnote: 6

Endangered Species Act, 16 U.S.C. §§ 1531-1544 (1988 & Supp. 1993); National Forest Management Act, 16 U.S.C. §§ 1600-1687 (1988 & Supp. 1993). The ESA states that various species threatened with extinction "are of esthetic, ecological, educational, historical, recreational, and scientific value to the Nation and its people." 16 U.S.C. § 1533(a)(3).

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Footnote: 7

*See, e.g.*, Sierra Club v. Froehlke, 816 F.2d 205 (5th Cir. 1987)(party opposing construction must prove the inadequacy of the builder's environmental impact statement).

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Footnote: 8

16 U.S.C. § 1533(b)(3)(A). ("[A]fter receiving the petition of an interested person . . . to add a species to [the endangered or threatened species list], the Secretary shall make a finding as to whether the petition presents substantial scientific or commercial information indicating that the petitioned action may be warranted.").

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Shrader-Frechette, *supra* note 5, at 98.

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Footnote: 13

*Id.*

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*See* 16 U.S.C. § 1533.

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Footnote: 22

Thomas et al., *supra* note 14, at 23.

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Footnote: 23

Soulé & Simberloff, *supra* note 16, at 32-33.

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Footnote: 24

*Id.* at 19-40.

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Footnote: 25

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Footnote: 26

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*See generally* Metapopulation Dynamics: Empirical and Theoretical Investigations (M.E. Gilpin & I. Hanski eds., 1991).

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