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ABSTRACT

National wildlife refuges have a biological conservation mandate surpassing that of any other category of public land in the United States. The National Wildlife Refuge System Improvement Act of 1997 forged a statutory requirement to maintain the biological integrity, diversity, and environmental health of refuges. Yet, considerably more guidance from science is needed if this mandate is to be interpreted in a scientifically defensible and biologically conservative manner. After evaluation of the extent to which well-accepted goals and principles of conservation biology are reflected in the wildlife refuge system mandate and in the actual design and management of refuges, it is evident that connections of refuges and other reserves across regional landscapes and better integration of refuge management with surrounding land uses are needed to enhance the conservation mission of refuges. A careful interpretation of biological (or ecological) integrity, biodiversity, and health in establishing policies for refuges and in indicator selection, monitoring, and adaptive management is essential. Integrity, the broadest of the three concepts invoked in the new mandate, incorporates notions of wholeness (or intactness or completeness), resistance to stress, and resilience – the capacity to bounce back after a disturbance. Measuring the position and movement of refuges along a complex gradient of relatively pristine to highly degraded requires well-selected indicators and a rigorous monitoring design. Finally, the spirit of the new mandate can be fully realized only when managers and policy makers embrace the land ethic of Aldo Leopold and are willing and able to think bigger in space, time, and ambition.

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INTRODUCTION

Unlike national parks, wilderness areas, and many other categories of protected areas in the United States, national wildlife refuges were set aside with wildlife, wild lands, and scientific principles for management clearly in mind. National wildlife refuges were established to "provide, preserve, restore and manage a national network of lands and waters sufficient in size, diversity and location to meet society's needs for areas where the widest spectrum of benefits associated with wildlife and wildlands is enhanced and made available."[1] The four major objectives of the refuges were to protect habitat of endangered species, to perpetuate migratory bird populations, to preserve natural diversity of all animals and migratory birds, and to engender an understanding and appreciation of wildlife.[2] The more specific objectives of the refuge system must evolve through time to keep pace with the accelerating loss and degradation of biodiversity and ecological function. Objectives must also reflect growing understanding of the role of protected areas in the conservation of biodiversity and the management policies and practices that best promote that role.

Biological diversity (biodiversity), biological or ecological integrity, ecosystem health, and sustainability are among the primary buzzwords or "umbrella" concepts[3] currently used to describe a desirable state of ecosystems and to track departures from that state. These terms have been applied by different authors and in different contexts in a bewildering and often inconsistent variety of ways, such that their meaning is often unclear. Integrity and health are arguably the fuzziest of all the buzzwords, such that some ecologists eschew any use of these terms. Yet, for those scientists who aspire to make their work meaningful to the public and applicable to the real world, these terms cannot be avoided as they are deeply embedded in environmental policy. Ecological integrity has been a policy objective in several national and bi-national laws and agreements, including the U.S. Water Quality Amendments of 1972 (Clean Water Act), the Great Lakes Water Quality Agreement between the United States and Canada, and the Canadian National Parks Act.[4] Of particular relevance to the topic of this article,

1. DYAN ZASLOWSKY & THE WILDERNESS SOCIETY, THESE AMERICAN LANDS 157 (1986); *see* National Wildlife Refuge System Administration Act of 1966, 16 U.S.C. §§ 668dd-668ee (2000).

2. *Id.*

3. Reed F. Noss, *Ecological Integrity and Sustainability: Buzzwords in Conflict?, in* PERSPECTIVES ON ECOLOGICAL INTEGRITY 60 (Laura Westra & John Lemons eds., 1995).

4. *See generally* STEPHEN WOODLEY ET AL., ECOLOGICAL INTEGRITY AND THE MANAGEMENT OF ECOSYSTEMS (1993); WAYNE S. DAVIS & THOMAS P. SIMON, BIOLOGICAL

the National Wildlife Refuge System Improvement Act of 1997 mandates that the U.S. Fish and Wildlife Service "ensure that the biological integrity, diversity, and environmental health of the System are maintained."[5] In acting upon this mandate, managers of the national wildlife refuge system must take care to apply sound methods, in both interpretation and practice, in maintaining the integrity, diversity, and health of the refuges. This is best achieved though accurate monitoring of the refuge's integrity and by adhering to the greater goals of conservation.

CONSERVATION GOALS

The requirement to maintain biological integrity, diversity, and environmental health on national wildlife refuges is compatible with the goals of conservationists worldwide. Noss and Cooperrider reviewed and synthesized numerous conservation approaches and stated four goals that are "consistent with the overarching goal of maintaining the native biodiversity of a region in perpetuity."[6] In slightly modified form, these well-accepted goals are (1) represent all kinds of ecosystems, across their natural range of variation, in protected areas; (2) maintain viable populations of all native species in natural patterns of abundance and distribution; (3) sustain ecological and evolutionary processes within their natural ranges of variability; and (4) build a conservation network that is adaptable and resilient to environmental change.

Several implications can be drawn from these goals in terms of building and managing a network of national wildlife refuges. First, the goal of representing all types of ecosystems is one of the oldest goals of conservation, extending back to the late nineteenth century in Australia and the early twentieth century in North America.[7] This goal is consistent with the original purpose of the national wildlife refuge system to preserve areas where the "widest spectrum of benefits associated with wildlife and wildlands is enhanced and made available." Protecting a full range of environmental variation in refuges will help ensure that species, genetic variation, communities, and other elements of biodiversity—many of which are poorly known—are represented in

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ASSESSMENT AND CRITERIA: TOOLS FOR WATER RESOURCE PLANNING AND DECISION MAKING (1995).

5. 16 U.S.C. § 668dd(a)(4)(B) (2000).

6. REED F. NOSS & ALLEN Y. COOPERRIDER, SAVING NATURE'S LEGACY: PROTECTING AND RESTORING BIODIVERSITY 89-90 (1994).

7. *See generally* ROBERT CROKER, PIONEER ECOLOGIST (1991); J. Michael Scott, *A Representative Biological Reserve System for the United States?*, NEWSLETTER (Soc'y for Conservation Biology, Arlington, Va.), May 1999, at 1.

the refuge system. A "gap analysis"[8] of refuges against maps of current vegetation can be used to assess how well the nation's ecosystems and associated biodiversity are represented in refuges. Auspiciously, the refuge system already encompasses a greater variety of ecosystems than any other federal land system.[9] Representation, however, is still far from balanced. Those ecosystems poorly represented constitute the gaps that need filling. A further consideration of historical vegetation cover and its changes through time helps illuminate "endangered ecosystems" that have declined in area or quality substantially since European settlement[10] and warrant proportionately greater representation—and restoration—in the refuge system today. I am not aware of any such analysis being undertaken for the national wildlife refuge system. The most intelligent approach is probably to address the issue nationwide for all categories of protected and managed areas and, from the results, determine the proper role of the refuges in relation to other lands in filling gaps in representation and restoration.

The second goal presented by Noss and Cooperrider, maintaining viable populations of native species, underlies a large part of the research agenda in conservation biology today and is implicit in the objectives of the refuge system to protect habitat of endangered species, perpetuate migratory bird populations, and preserve natural diversity of all animals and migratory birds. Population viability analysis (PVA), in its various forms, is the tool that conservation biologists use to estimate the probability of particular populations persisting for some time period and the relative chances of persistence or population growth under different management regimes or alternative future scenarios,[11] which is more enlightening in many cases. Much more could be done to examine population viability issues on national wildlife refuges. For example, the Greater Sage-Grouse, an imperiled species for which a petition has been submitted for listing under the U.S. Endangered Species Act, occurs on some national wildlife refuges and is sensitive to livestock grazing and other causes of degradation of its sagebrush steppe habitat. Population viability of the grouse could be modeled under alternative scenarios of refuge management, including

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8. J. Michael Scott et al., *Gap Analysis: A Geographic Approach to Protection of Biological Diversity*, 123 WILDLIFE MONOGRAPHS 1, 5 (1993).

9. ROBERT L. FISCHMAN, THE NATIONAL WILDLIFE REFUGES: COORDINATING A CONSERVATION SYSTEM THROUGH LAW, at xi (2003).

10. *See generally* REED F. NOSS ET AL., ENDANGERED ECOSYSTEMS OF THE UNITED STATES (1995).

11. For recent reviews of PVA, see POPULATION VIABILITY ANALYSIS (Steven R. Beissinger & Dale R. McCullough eds., 2002) and J. Michael Reed et al., *Emerging Issues in Population Viability Analysis*, 16 CONSERVATION BIOLOGY 7 (2002).

cessation (or resumption) of livestock grazing, active control of invasive non-native plants, human recreational pressure, and so on, to predict responses of the grouse population. Such predictions require a relatively thorough understanding of grouse habitat requirements, effects of various land uses and other factors on key habitat variables, and demographic responses of grouse to habitat change, but such information is just beginning to emerge for this species.[12] Nevertheless, because Greater Sage-Grouse are area-limited and require enormous landscapes to maintain viable populations, management of refuges should be considered jointly with management of surrounding lands (*e.g.*, Bureau of Land Management and Forest Service lands) where most of the grouse occur.

Coordination across vast scales is even more urgent with respect to the American pronghorn, which surpasses the sage grouse in its area requirements. Refuges established for pronghorn, for example Hart Mountain in Oregon (269,924 acres) and Sheldon in Nevada and Oregon (573,504 acres), which are separated by approximately 30 miles, are probably not large enough, either alone or in combination, to sustain a viable population of pronghorn, especially since only a percentage of the refuge area constitutes suitable pronghorn habitat. Most small herds of pronghorn have ranges approximately five to ten miles wide,[13] and the distance between summer and winter ranges may be as much as 100 miles.[14] Long-term viable populations of vertebrates like the pronghorn generally include thousands to tens of thousands of individuals.[15] These examples highlight the need to expand beyond individual refuges and consider the conservation and management of broad regions when addressing issues of population viability, especially because many species are distributed as metapopulations, *i.e.*, groups of populations linked by occasional dispersal.[16] Refuge managers should cooperate with surrounding land managers, both public and private, to assure that the overall landscape provides suitable habitat conditions to provide

12. *See generally* Michael J. Wisdom et al., *Performance of Greater Sage-Grouse Models for Conservation Assessment in the Interior Columbia Basin, U.S.A.*, 16 CONSERVATION BIOLOGY 1232 (2002).

13. James D. Yoakum, *Pronghorn*, *in* BIG GAME OF NORTH AMERICA 103, 108–14 (John L. Schmidt & Douglas L. Gilbert eds., 1978) (a square range 10 miles wide would encompass 64,000 acres).

14. Bart W. O'Gara, *Mammalian Species, No. 90*, THE AM. SOC'Y OF MAMMALOGISTS 1, 4 (1978).

15. As concluded by several authors in VIABLE POPULATIONS FOR CONSERVATION (Michael E. Soulé ed., 1987).

16. As a general reference, see ILLKA HANSKI, METAPOPULATION ECOLOGY 2-3, 182 (1999).

functional connectivity among refuges, other protected areas, and other suitable habitat for the species of concern.

The goal of sustaining ecological and evolutionary processes within a natural range of variability, third of the Noss and Cooperrider goals, is recognized as fundamental by ecologists because species evolve under a particular range of conditions, which must not be exceeded (at least not by too much or too quickly for natural selection to operate) if these species are to persist.[17] Ecological and evolutionary processes are what generate biodiversity and are fundamental to the ecological integrity of every landscape. Nevertheless, many ecologists believe that natural processes are given short shrift in land management, where managers are often more concerned with producing end-points or objects (*e.g.*, ducks, deer, timber, scenic views) than with sustaining fundamental processes. An exception, perhaps, is prescribed burning, which has a long history of use by Native Americans and more recent land managers to produce particular objects (*e.g.*, quail) or conditions (*e.g.*, open understories to facilitate hunting), but which is now used in many cases to maintain or restore healthy ecosystems.[18] There is no mention of maintaining ecological processes in the original objectives of the national wildlife refuge system, albeit some managers do apply prescribed burns and manipulations of hydrology to benefit waterfowl on refuges.[19]

The fourth goal listed by Noss and Cooperrider, building a conservation network that is adaptable and resilient to environmental change, requires some explanation. Until recently, conservationists and land managers mostly operated under what has been called an "equilibrium" paradigm of nature, where disturbed areas gradually and predictably return to a climax condition, which in turn is stable over a long period of time. This view of nature has been largely rejected by ecologists and replaced by a "non-equilibrium" view, where ecosystems are seen as much more variable, less stable, and never static.[20]

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17. Peter B. Landres et al., *Overview of the Use of Natural Variability Concepts in Managing Ecological Systems*, 9 ECOLOGICAL APPLICATIONS 1179 (1999).

18. *See generally* STEPHEN J. PYNE, FIRE IN AMERICA: A CULTURAL HISTORY OF WILDLAND AND RURAL FIRE (1982); Jerry F. Franklin & James K. Agee, *Forging a Science-Based National Forest Fire Policy*, 20 ISSUES SCI. & TECH. 59 (2003), *available at* http://www.issues.org/issues/20.1/franklin.html (last visited Nov. 17, 2004).

19. Personal observation.

20. DANIEL B. BOTKIN, DISCORDANT HARMONIES: A NEW ECOLOGY FOR THE TWENTY-FIRST CENTURY (1990); Steward T.A. Pickett et al., *The New Paradigm in Ecology: Implications for Conservation Above the Species Level*, *in* CONSERVATION BIOLOGY: THE THEORY AND PRACTICE OF NATURE CONSERVATION, PRESERVATION AND MANAGEMENT 66 (Peggy L. Fiedler & Subodh K. Jain eds., 1992).

Hence, the old concept of putting a fence around a protected area and expecting it to take care of itself, remaining in climax condition for perpetuity, has been replaced by the recognition that active management of a protected area is often required to sustain desired conditions. Moreover, the realization that climate is changing rapidly due to the accumulation of greenhouse gases in the atmosphere[21] suggests that those who select, design, and manage national wildlife refuges and other conservation areas must take into account factors that will make species and ecosystems more or less adaptable or resilient to this change. Migration, rather than in-situ evolution, appears to be how most species responded to past climate changes.[22] Habitat fragmentation at a range of spatial scales (*e.g.*, from a road built through a forest to massive deforestation of a region) will make it more difficult for all but the most vagile species to migrate in response to shifting habitat conditions.[23] Changes in disturbance regimes (*e.g.*, fire frequency or intensity) and increased invasion of non-native species are also expected during the present warming trend. Therefore, planners and managers will have to consider such measures as increasing habitat connectivity among refuges by corridors or other means, reducing the density of roads and other avenues of non-native species invasion, and protecting climatic refugia.[24]

Although the over-riding goal of most modern conservation strategies is to maintain biodiversity, the interpretation of this goal in practice is not straightforward. Conservationists appreciate that the earth's biodiversity is dynamic, changing over time as species and other taxa go extinct and new taxa evolve. The rate of speciation has been generally higher than the rate of extinction, except during a few mass extinction episodes, so that the number of species worldwide has been

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21. *See generally* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 1995—IMPACTS, ADAPTATIONS AND MITIGATION OF CLIMATE CHANGE: SCIENTIFIC-TECHNICAL ANALYSES (Robert T. Watson et al. eds., 1996).

22. For examples, see G.R. Coope, *Late-Cenozoic Fossil Coleoptera: Evolution, Biogeography, and Ecology*, 10 ANN. REV. ECOLOGY & SYSTEMATICS 247 (1979), and Ary A. Hoffman & Miriam J. Hercus, *Environmental Stress as an Evolutionary Force*, 50 BIOSCIENCE 217 (2000).

23. Habitat fragmentation is the process whereby intact blocks of habitat are broken into smaller and more isolated pieces, for example by agriculture, logging, urban development, or highways. *See* Reed F. Noss & Blair Csuti, *Habitat Fragmentation*, *in* PRINCIPLES OF CONSERVATION BIOLOGY 269 (Gary K. Meffe & C. Ronald Carroll eds., 1997).

24. *See generally* Robert L. Peters & Joan D.S. Darling, *The Greenhouse Effect and Nature Reserves*, 35 BIOSCIENCE 707 (1985); Reed F. Noss, *Beyond Kyoto: Forest Management in a Time of Rapid Climate Change*, 15 CONSERVATION BIOLOGY 578 (2001).

rising throughout most of the history of life.[25] Today, almost all biologists agree that we are well into the sixth great mass extinction event in the history of life, with the current extinction rate vastly surpassing the rate of speciation.[26] The policy implications of this realization, which have not dawned on most of the public or politicians, is that safeguarding biodiversity and the creative processes that generate it is arguably the highest and most urgent mission of our civilization.[27]

If few people recognize the need to conserve biodiversity, fewer still recognize the ways in which biodiversity is often misunderstood and misrepresented, sometimes intentionally, by policy makers, developers, and even land managers. How many times have we heard land managers or developers claim that a particular action, such as a timber sale or a recreational or residential development, will increase biodiversity? To illustrate how such a misrepresentation is created, consider that urbanization threatens more species in the United States than any other activity,[28] yet species richness often peaks in locations with an intermediate degree of urban development, such as suburbs. However, a high proportion of the species found in these areas are relatively ubiquitous and tolerant of human activities, whereas many of the more sensitive native species are restricted to areas with relatively little development.[29]

Species richness, which is what most people have in mind when they use the term biodiversity, generally refers to the number of species in a defined area. By itself, species richness says nothing about the kinds of species in the area or their relative abundances, geographic ranges, functional roles, residency, or conservation status. It provides no information on age structure, sex ratio, survival, reproduction, or population viability of the species present. Proper use of the species richness concept in conservation must take into account the qualitative aspects of species in a defined area, what is commonly known as species composition. A site dominated by weedy, exotic, or opportunistic species is not equivalent to a site with an equal number of species, but virtually

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25. *See generally* David Jablonski, *Extinctions in the Fossil Record*, *in* EXTINCTION RATES 25 (John H. Lawton & Robert M. May eds., 1995).

26. *See generally* EDWARD O. WILSON, THE DIVERSITY OF LIFE (1992); EXTINCTION RATES, *supra* note 25.

27. That we have not recognized the urgency of conservation action is testimony to the poor education provided by our school systems and the mass media.

28. Brian Czech et al., *Economic Associations Among Causes of Species Endangerment in the United States*, 50 BIOSCIENCE 593, 595 (2000).

29. Michael L. McKinney, *Urbanization, Biodiversity, and Conservation*, 52 BIOSCIENCE 883, 887–88 (2002).

all of which are native and characteristic of the region in question.[30] Moreover, species richness is dynamic, such that areas that currently support a large number of species may not necessarily support a large number of species in the future, for a number of reasons. For example, the area, because of recent development surrounding it or a variety of deleterious activities occurring inside it, may not be able to sustain viable populations of many of the species currently found there. Or, because of rising sea levels, a coastal area with high biodiversity relatively soon may be under water.

Also not well appreciated is that most formal definitions of biodiversity include not just species richness, but structural, functional, and compositional components of ecosystems at multiple levels of organization, from genes to populations to landscapes.[31] For example, the structural architecture of a redwood forest is a component of biodiversity, as is the genetic diversity of a local species of snail, the complex mosaic of vegetation patches across a landscape, and the dynamic processes that generate those structures and patterns. Some have argued that including processes and physical structures in the definition of biodiversity is pushing the concept too far, *i.e.*, these are not truly "living" components, so how can they be part of "bio" diversity?[32] The counter-argument is that the separation of living and non-living nature is artificial. As recognized in the original conceptualization of the ecosystem by Tansley,[33] these components of nature are interdependent and constantly in flux. What is organism today is environment tomorrow, and vice versa.

INTEGRITY: WHOLENESS, RESISTANCE, AND RESILIENCE

Of the three concepts—integrity, diversity, and health—invoked in the 1997 statutory requirement for managing national wildlife refuges, integrity is the broadest and by most definitions encompasses the other two. The first reference to integrity in the environmental literature was Aldo Leopold's famous statement in his essay on land ethics: "A thing is right when it tends to preserve the integrity, stability, and beauty of the

30. Jared M. Diamond, *Island Biogeography and Conservation: Strategy and Limitations*, 193 SCIENCE 1027 (1976); Reed F. Noss, *A Regional Landscape Approach to Maintain Diversity*, 33 BIOSCIENCE 700, 701-02 (1983).

31. Reed F. Noss, *Indicators for Monitoring Biodiversity: A Hierarchical Approach*, 4 CONSERVATION BIOLOGY 355, 356-57 (1990).

32. Paul L. Angermeier & James R. Karr, *Biological Integrity Versus Biological Diversity as Policy Directives*, 44 BIOSCIENCE 690, 694 (1994).

33. A.G. Tansley, *The Use and Abuse of Vegetational Concepts and Terms*, 16 ECOLOGY 284, 303-04 (1935).

biotic community. It is wrong when it tends otherwise."[34] As noted by Holmes Rolston, "Those memorable words remarkably blend facts and values, biology and ethics, because whether or not an ecosystem is stable and integrated is, first, a matter of descriptive fact, if also, secondly, a matter of evaluation and prescription."[35] Leopold never explained what he meant by integrity, and it was several decades later before the concept appeared again in the environmental literature.

Conspicuous in most definitions of integrity are notions of wholeness (alternately, intactness or completeness) of an ecosystem, naturalness or absence of substantial human modification, and an ability to withstand or bounce back from perturbation.[36] By contrast, biologically diverse ecosystems are not necessarily natural; they may be comprised largely of non-native species (which is why, as I argued above, adjectives such as "native" should be attached to species richness or biodiversity in order to guide conservation and management in a desirable direction). Similarly, an ecosystem can be healthy, in the sense of producing biomass through photosynthesis, cycling nutrients, and other measures of functionality, even if modified substantially from natural conditions by human actions.

In order to clarify and reconcile the meaning of integrity and health, especially with respect to the new mandate for national wildlife refuges, I suggest we focus on three fundamental qualities: wholeness, resistance, and resilience.[37] Wholeness is best interpreted simply as containing the entire and characteristic suite of biological elements (species, communities, genotypes, etc.) and processes that we would expect in a given type of ecosystem, assuming it is large enough to sustain all of these elements and has not been significantly degraded by human actions. For example, wholeness implies intact food webs replete with large carnivores and natural disturbance regimes operating as they have for centuries or millennia. Of course, many regions of the earth no longer contain any areas that meet these criteria in a strict sense, but that does not diminish the value of wholeness as an ideal for protection, restoration, and management of national wildlife refuges as components of broad, inter-linked networks of protected areas. The concept of "re-wilding" explicitly incorporates the idea of guiding regional landscapes

34. ALDO LEOPOLD, A SAND COUNTY ALMANAC AND SKETCHES HERE AND THERE 224-25 (Oxford Univ. Press 1969) (1949).

35. Holmes Rolston III, *Foreword* to LAURA WESTRA, AN ENVIRONMENTAL PROPOSAL FOR ETHICS: THE PRINCIPLE OF INTEGRITY, at xi (1994).

36. *See, e.g.*, Laura Westra et al., *Ecological Integrity and the Aims of the Global Integrity Project*, *in* ECOLOGICAL INTEGRITY 19, *passim* (David Pimentel et al. eds., 2000).

37. *See generally* ECOLOGICAL INTEGRITY, *id.*

toward renewed wholeness, even if that takes many decades to accomplish.[38]

Resistance and resilience are familiar terms in the lexicon of ecology, but they, too, have suffered from vague or conflicting definitions. Both terms refer to the stability of ecosystems. Resistance is most commonly understood as the ability of a system to remain relatively unchanged when subjected to disturbance or stress, whereas resilience is the ability to bounce back from disturbance, as measured by the rate of return to the reference state.[39] Holling, however, has defined resilience as essentially equivalent to resistance.[40] Adding to the confusion, resistance and resilience may be negatively correlated, such that one property increases as the other decreases, or, alternately, they may increase or decrease in unison.[41] Nevertheless, when viewed at a broad spatial scale, for example a national wildlife refuge and the surrounding landscape matrix, it is reasonable to predict that an intact ecosystem will be both more resistant and resilient to stress than an ecosystem fragmented and degraded by human activities. Among the properties of ecosystems that enhance resistance and/or resilience are (1) a diversity of functional groups, (2) high or characteristic species richness and redundancy within functional groups, and (3) keystone or highly interactive species persisting as ecologically effective populations.[42] Importantly, these three criteria are likely to be met only where individual refuges are very large in size (*e.g.*, the Arctic National Wildlife Refuge at 19.3 million acres and the Yukon Delta National Wildlife Refuge at 19.5 million acres[43]), embedded in a substantial matrix of well-managed land, and managed explicitly for their native biodiversity.

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38. Michael Soulé & Reed Noss, *Rewilding and Biodiversity: Complementary Goals for Continental Conservation*, WILD EARTH, Fall 1998, at 18.

39. *See* STUART L. PIMM, THE BALANCE OF NATURE? 18-34 (1991); Volker Grimm & Christian Wissel, *Babel, or the Ecological Stability Discussions: An Inventory and Analysis of Terminology and a Guide to Avoiding Confusion*, 109 OECOLOGIA 323, 329 (1997).

40. *See generally* C.S. Holling, *Resilience and Stability of Ecological Systems*, 4 ANN. REV. ECOLOGY & SYSTEMATICS 1 (1973).

41. *See generally* D.L. DeAngelis et al., *Nutrient Dynamics and Food Web Stability*, 20 ANN. REV. ECOLOGY & SYSTEMATICS 71 (1989); Darrell A. Herbert et al., *Hurricane Damage to a Hawaiian Forest: Nutrient Supply Rate Affects Resistance and Resilience*, 80 ECOLOGY 908 (1999); W.G. Whitford et al., *Using Resistance and Resilience Measurements for "Fitness" Tests in Ecosystem Health*, 57 J. ENVTL. MGMT. 21 (1999).

42. *See generally* Noss, *supra* note 24; Michael E. Soulé et al., *Ecological Effectiveness: Conservation Goals for Interactive Species*, 17 CONSERVATION BIOLOGY 1238 (2003).

43. Robert Fischman, *The Crazy-Quilt Refuge System*, WILD EARTH, Winter 2003-2004, at 38, 40.

A challenge to the notion of maintaining ecological integrity and all it implies in national wildlife refuges (or anywhere) is the modern scientific understanding that nature is not in equilibrium. As I noted earlier, the classical "balance of nature" paradigm has been rejected by most ecologists in favor of a contemporary paradigm that emphasizes shifting, non-equilibrium conditions, open systems (and hence the importance of context as well as content), and process as opposed to endpoint.[44] Some pro-development zealots gleefully promote this new paradigm without understanding its nuances. Among the most critical qualifiers to the idea that nature is open-ended and always changing is the recognition that natural selection has equipped species with adaptability to change only within certain bounds. Therefore, we must be careful not to exceed those bounds. Dan Botkin, much adored by some in the "Wise Use" movement for his challenge of conventional preservationist goals, nevertheless recognizes that "to accept certain kinds of change is not to accept all kinds of change...certain rates of change are natural, desirable, and acceptable, while others are not."[45] Or as Steward Pickett and coauthors put it, "Human-generated changes must be constrained because nature has *functional, historical,* and *evolutionary* limits."[46] Certainly these limits have been exceeded in earth's history—these are the mass extinction events mentioned earlier. If we are to halt the current mass extinction, which is an opportunity unique to our generation, we must recognize and adhere to limits. Such recognition is entirely consistent with the mandate to maintain biological integrity, diversity, and environmental health in the national wildlife refuges.

MEASURING AND MANAGING INTEGRITY

To be a meaningful concept for guiding policies and practices on national wildlife refuges, integrity must be amenable to measurement, monitoring, score-keeping, and adaptive management. We need to be able to determine whether or not we are successfully managing national wildlife refuges to maintain their integrity, and, if not, we must be able to change management in a direction that provides a higher probability of success. Indeed, the 1997 Improvement Act requires the U.S. Fish and Wildlife Service to "monitor the status and trends of fish, wildlife, and

44. BOTKIN, *supra* note 20, at 145–47; Pickett et al., *supra* note 20.
45. BOTKIN, *supra* note 20, at 11–12.
46. Pickett et al., *supra* note 20, at 82.

plants in each refuge."[47] The literature on indicators for monitoring and assessing biodiversity, ecological integrity, health, and related qualities is immense. Despite the complexities involved, the task of selecting and employing informative indicators is imperative. Without good indicators, effective monitoring and adaptive management are impossible, as is the ability to learn from successes or mistakes. The first phase in monitoring for adaptive management of ecological integrity is scoping, which includes (1) identifying the management issues and questions, *e.g.*, what specific prescribed burning regime will produce the habitat structure required by the species of interest?; and (2) relating management objectives to broader conservation goals in a tiered fashion.[48] Then comes the phase of experimental (monitoring program) design, where indicators are selected, a sampling protocol that includes replication of treatments and controls is established, and management thresholds (*i.e.*, points where management must be changed to avoid risk to biodiversity) are identified.[49]

Most experts agree that when monitoring general qualities of ecosystems, such as biodiversity or integrity, multiple indicators are necessary, covering various spatial scales and levels of biological organization.[50] Indicators developed at a site scale (say, 10–100 acres) are unlikely to be informative at a landscape scale of thousands or more acres, which is the scale of most national wildlife refuges. While multiple indicators are needed to encompass the complexity of ecosystems at broad scales, in order for monitoring to be affordable, the list of potentially useful indicators must either be narrowed to a few that provide the most useful information at a low cost or collapsed to a single, multi-metric index. The only thoroughly tested and well-accepted index of biological or ecological integrity is Karr's index of biological integrity or IBI,[51] and this index has been applied most effectively to streams. No corresponding terrestrial index of ecological integrity—or better yet, an index to measure the integrity of an entire landscape or region, with both terrestrial and aquatic components—is well tested or accepted. Nevertheless, the general attributes of an acceptable index have been recognized,[52] and considerable research has demonstrated the

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47. National Wildlife Refuge System Improvement Act of 1997, Pub. L. No. 105-57, § 5(a)(4)(N), 114 Stat. 1252, 1256.

48. NOSS & COOPERRIDER, *supra* note 6, at 298-324.

49. *Id.*

50. *See generally* Noss, *supra* note 31, at 355.

51. *See generally* JAMES R. KARR & ELLEN W. CHU, RESTORING LIFE IN RUNNING WATERS: BETTER BIOLOGICAL MONITORING (1999).

52. *See generally* James K. Andreasen et al., *Considerations for the Development of a Terrestrial Index of Ecological Integrity*, 1 ECOLOGICAL INDICATORS 21 (2001).

utility of certain groups of organisms (*e.g.*, birds) for measuring differences in integrity between terrestrial or wetland reference sites in non-degraded condition and sites with varying levels of human impact.[53] A "floristic quality index," which measures the degree to which plant species present at a site reflect non-degraded conditions, is proving useful at small spatial scales, but is dependent on field personnel with strong taxonomic skills and has not been tested at broad scales.[54]

When selecting species as indicators, it is crucial that multiple species representing a variety of taxa and life histories are included, that selection of species is based on quantitative data from the region of interest, and that population trends be interpreted cautiously to distinguish real signals from "noise" that is unrelated to ecological integrity.[55] Furthermore, if information from multiple species or other attributes of ecosystems (*e.g.*, habitat structures) is collapsed into a multimetric index, the question of how to integrate metrics (*i.e.*, sum, arithmetic mean, weighted average, graphic display, multivariate statistics, ecosystem model, or some other means) must be addressed carefully, and there is no consensus as to which approach is best. It is also critical that information from individual metrics not be lost or "eclipsed." For instance, two areas could have identical overall index values, but Area A has intermediate values for all attributes, while Area B has some attributes in excellent condition and other attributes in poor condition. A simple pie diagram is one way to illustrate the values of all attributes in an index, while retaining information on each individual metric (Figure 1).[56]

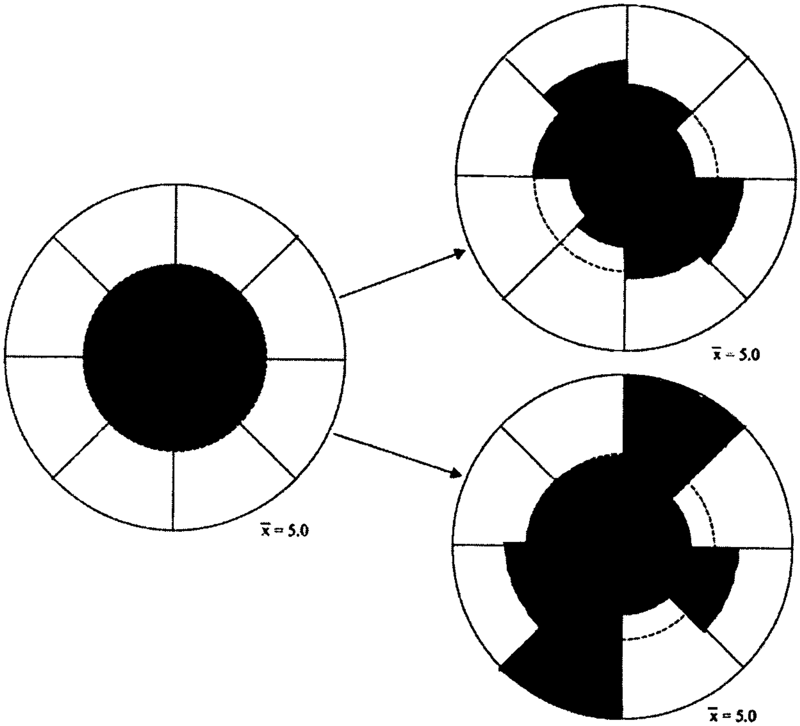
53. *See, e.g.*, Robert P. Brooks et al., *Towards a Regional Index of Biological Integrity: The Example of Forested Riparian Ecosystems*, 51 ENVTL. MONITORING & ASSESSMENT 131, 133–35 (1998); T.J. O'Connell et al., *A Bird Community Index of Biotic Integrity for the Mid-Atlantic Highlands*, 51 ENVTL. MONITORING & ASSESSMENT 145, 145–46 (1998); OFFICE OF WATER, U.S. ENVTL. PROT. AGENCY, METHODS FOR EVALUATING WETLAND CONDITION: # 13 BIOLOGICAL ASSESSMENT METHODS FOR BIRDS EPA-822-R-02-023 (2002), *available at* http://www.epa.gov/waterscience/criteria/wetlands/13Birds.pdf (last visited Nov. 17, 2004).

54. Thomas P. Rooney & David A. Rogers, *The Modified Floristic Quality Index*, 22 NAT. AREAS J. 340, 340, 342–43 (2002).

55. *See generally* Vincent Carignan & Marc-André Villard, *Selecting Indicator Species to Monitor Ecological Integrity: A Review*, 78 ENVTL. MONITORING & ASSESSMENT 45 (2002).

56. Andreasen et al., *supra* note 52.

Figure 1: Use of a Pie Diagram to Integrate Metrics into an Index without Eclipsing Information from Individual Metrics



A major effort to measure and monitor ecological integrity at the scale of ecoregions, or portions thereof, is an "assessment of target viability" methodology being developed and tested by The Nature Conservancy in several regions of North America. This process begins with identifying the "focal conservation targets" (*i.e.*, a limited set of species, natural communities, or ecological systems chosen to represent the biodiversity of an area), then proceeds to identifying the "key ecological attributes" that most clearly define or characterize the target, limit its distribution, or determine its variation over space and time. Measurable indicators are then selected for each target, with the selection criteria emphasizing biological relevance, sensitivity to anthropogenic stress, ability to provide an early warning of change, measurability, and cost effectiveness. Indicators are measured for the area of concern and used to rate condition as very good, good, fair, or poor.[57] As an example, one of the seven conservation targets for the Apalachicola River watershed and estuary in Florida is shallow barrier island estuaries, with "subtargets" being oyster reefs, seagrass beds, and tidal flats. The key ecological attribute for oyster reefs is water quality, with salinity and freshwater inflows as the indicators. For seagrass beds, water quality and habitat size are both key attributes, with light penetration, salinity, and percent seagrass cover as indicators. Tidal flats have the same two key attributes, but the indicators are waterfowl abundance, polychaete density and richness, and salinity.[58]

Arguably more useful than a snapshot assessment of ecological integrity at any point in time is an evaluation of the direction in which the ecosystem is moving along a complex gradient from relatively pristine to highly degraded conditions. The desired direction of movement for national wildlife refuges, given the integrity/diversity/health mandate, would be toward the pristine or historic condition, recognizing, however, that a return to a pre-European settlement or totally pristine condition would not necessarily be appropriate or even possible. For instance, the landscape matrix in which refuges are embedded has, in many cases, changed radically since settlement, which limits the ability of refuges to function optimally as self-sustaining ecosystems. Moreover, the present climate is already considerably different from the climate of 200-plus years ago, such that the conditions for plant establishment today are different from in the past. Nevertheless, a goal of reversing the trajectories of landscape change associated with biotic impoverishment is quite appropriate for refuges. We know, for example, that such trends as loss of forest cover and other natural habitat, fragmentation of habitat, increasing roads and traffic, and invasion of non-native species have been associated with loss of native biodiversity and ecological integrity[59] (Figure 2). In particular cases, specific trends such as fire suppression or wetland drainage can be identified as most damaging. Reversing these trends as far as is feasible, and monitoring progress along the way with the help of carefully selected indicators, is a valid standard for adaptive management of national wildlife refuges. In most regions, conservationists cannot be satisfied with the best remaining sites as representing reference

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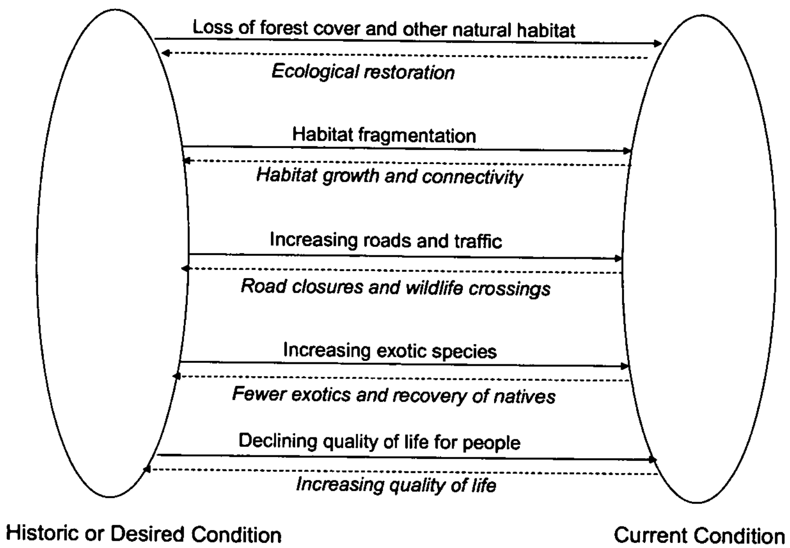
57. *See generally* Jeffrey D. Parrish et al., *Are We Conserving What We Say We Are? Measuring Ecological Integrity Within Protected Areas*, 53 BIOSCIENCE 851 (2003).

58. Results from a University of Central Florida graduate class project on conservation planning in the fall of 2003 (R.F. Noss, Professor).

59. David S. Wilcove et al., *Quantifying Threats to Imperiled Species in the United States*, 48 BIOSCIENCE 607, 607 (1998).

conditions. If ecological degradation continues at present rates, the standards for integrity will drop substantially with each generation. Hence the need for ecological recovery at broad scales.

Figure 2: A Conceptual Plan for Reversing Trends of Landscape Change That Have Been Associated with Biotic Impoverishment



THINKING BIG IN NATIONAL WILDLIFE REFUGE MANAGEMENT

To fulfill the true spirit of the mandate to maintain the biological integrity, diversity, and environmental health of the national wildlife refuges, managers and policy makers must be willing and able to think big in space, time, and ambition. They must be able to visualize the vast regional landscape of which refuges are functional components; consider the past, present, and future of refuge biota across thousands to millions of years; and dare to promote more visionary goals for the recovery of ecological integrity in refuges than any of their predecessors have championed.

Spatially, it is likely that refuges will serve their purposes more effectively if connected with other refuges and protected areas into an expansive, interactive network. Among the recognized functions of habitat connectivity are (1) providing for daily and seasonal movements of animals; (2) facilitating dispersal, gene flow, and rescue effects; (3) allowing for range shifts of species, as in response to climate change; and (4) maintaining flows of ecological processes (*e.g.*, fire, wind, sediments, water).[60] Importantly, a connected system of refuges can potentially be a whole greater than the sum of its parts. Although no single refuge might maintain viable populations of particular wide-ranging species, a well-connected network of refuges might maintain viable metapopulations. In designing linkages among refuges and other reserves, planners need to consider the mobility and dispersal characteristics of the species in question (generally, species sensitive to fragmentation on landscape to regional scales), other autecological characteristics (needs for food, cover, etc.) of those species, the structural characteristics and spatial pattern of the landscapes involved, the distance between patches of suitable habitat, presence of particular movement barriers (*e.g.*, highways), and the potential for interference from humans and natural predators. Although little is known about what constitutes a suitable corridor or movement habitat for most species, conservationists are not proposing that corridors be created to connect habitats that are naturally separated. Rather, the strategy is to maintain natural connections in the landscape or, where possible, to restore connections that have been severed by human activities.

Thinking bigger temporally involves considering the long-term trends in the landscapes, floras, and faunas that compose the present-day refuges. For example, Florida has many national wildlife refuges, most of which are coastal.[61] During various inter-glacial periods over the last few million years, sea level was much higher than today, and the only portions of Florida above water were the northern Highlands and the Brooksville, Lake Wales, and Atlantic Coastal Ridges.[62] The isolation of these ridges promoted speciation, especially on the Lake Wales Ridge (the most isolated), which is famous for its high density of endemic species.[63] These ridges must also have served as refugia for many terrestrial and freshwater taxa during marine incursions. For realistic conservation planning, we need to recognize that high sea levels are likely to return, perhaps within a century or two as a consequence of

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60. *See generally* NOSS & COOPERRIDER, *supra* note 6, at 150-56; Paul Beier & Reed F. Noss, *Do Habitat Corridors Provide Connectivity?*, 12 CONSERVATION BIOLOGY 1241 (1998); ANDREW F. BENNETT, LINKAGES IN THE LANDSCAPE (1999).

61. *See generally* FISCHMAN, *supra* note 9.

62. *See generally* ANTHONY F. RANDAZZO & DOUGLAS S. JONES, THE GEOLOGY OF FLORIDA (1997).

63. *See generally* Eric S. Menges, *Ecology and Conservation of Florida Scrub*, *in* R.C. ANDERSON ET AL., SAVANNA, BARRENS, AND ROCK OUTCROP PLANT COMMUNITIES OF NORTH AMERICA 7 (1998).

global warming. Hence, a sufficient degree of connectivity should be maintained or restored from the coast inland, so that species in coastal refuges can migrate to refugia on higher ground. Drastically increasing refuge (and other reserve) area on these ridges (*e.g.*, expanding the Lake Wales Ridge National Wildlife Refuge, which is presently only 1840 acres) is also a major priority.

A deep temporal perspective also would recognize the more recent changes in the landscape since European settlement, as discussed earlier. These changes have resulted in some kinds of ecosystems being much more endangered—in terms of the extent of decline in area and degradation of structure—than others. Among the most imperiled ecosystems in the United States are freshwater communities (*e.g.*, undammed rivers) and terrestrial communities that are dependent on frequent fire, such as longleaf pine and ponderosa pine savannas, oak savannas, grasslands, and many shrublands.[64] Restoration activities on national wildlife refuges should target these endangered ecosystems, as should new acquisitions or designations of refuges.

Finally, thinking big in national wildlife refuge management means setting ambitious goals that rest on a strong ethical foundation of obligations to nature. Charles Darwin believed that compassion for other living things is an extension of naturally selected moral sentiments. These sentiments evolved because they permitted harmonious interactions in groups.[65] Aldo Leopold went further, asserting that an extension of ethics to the land is "an evolutionary possibility and an ecological necessity."[66] Unless they are put into action, ethical principles are meaningless. For too long, national wildlife refuges and other public lands have been managed in an ethical vacuum, ignoring our obligations to other living things and our responsibility to restore the marvelous ecosystems that human actions have degraded. Managers have tried to accommodate multiple human uses of refuges without considering the primacy of the land. Now we have an explicit mandate to maintain (and by implication, to restore) biological integrity, diversity, and health. There is no turning back on that commitment.

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64. *See generally* NOSS ET AL., *supra* note 10.

65. *See generally* CHARLES DARWIN, THE DESCENT OF MAN AND SELECTION IN RELATION TO SEX (1871).

66. LEOPOLD, *supra* note 34, at 218.