# A DOZEN BIODIVERSITY PUZZLES

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## INTRODUCTION

The growing use of the word "biodiversity"[1] has called valuable attention to some of the most serious environmental issues that we and our succeeding generations will face,[2] but as the word begins to appear in the context of lawmaking we need to make sure that we understand what it actually means. Biodiversity, as will be discussed extensively below, is a blending of a motley variety of scientific ideas into a word so devoid of precision that it is nearly impossible to meaningfully quantify.[3] Using biodiversity as a legal standard may produce complex litigation that will be counterproductive to many environmentalists' goals of protecting endangered species and preventing future extinctions. It is time for lawmakers to begin to dissect the concept of biodiversity so that the young people who are being brought up to value "biodiversity" do not later become disillusioned when they learn that the ideas it contains are complex and sometimes conflicting.

The thesis of this Article is that the environmental and scientific issues implicated by the word "biodiversity" are very important, and should be considered in decision-making, but that the word biodiversity alone lacks the precision needed for a workable legal standard. The use of the term illustrates an understandable desire to emphasize the importance of conservation biology issues by defining them in the broadest and most inclusive terms, but such breadth invites the kind of multiple possible interpretations that hamper efficient administration and encourage wasteful litigation. If we wish to create a legally effective standard, we need to define our objectives as precisely as possible. If we don't, biodiversity is likely to end up as an effectively

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[1] *E.g.*, Peter J. Hogarth, *Overbiodiverse?*, 364 NATURE 664 (1993) (charting exponential growth in use of the term "biodiversity" in scientific paper titles between 1986 and 1993).

[2] *E.g.*, NAT'L RESEARCH COUNCIL, NATURE AND HUMAN SOCIETY: THE QUEST FOR A SUSTAINABLE WORLD 8 (Peter H. Raven ed., 1997) (Introduction to the Proceedings of the 1997 Convention on Biodiversity by the Board on Biology, stating "[B]iodiversity is . . . the key to our future sustainability. By understanding it, learning how to use it sustainably, protecting it, and preserving it, we shall be making a priceless gift to future generations and acting responsibly in the face of one of the greatest challenges that ever confronted humanity.").

[3] *See infra* Part II.

meaningless aspirational goal along the lines of the Clean Water Act's "national goal that the discharge of pollutants into the navigable waters be eliminated by 1985,"[4] or as an issue to be discussed in an environmental analysis and then disregarded.[5]

To create a legal standard with teeth, we will need to address the scientific issues that biologists recognize as inherent in the concept of biodiversity. After briefly discussing the history of the term biodiversity,[6] this Article provides a summary of some of the "puzzles" inherent in the concept of biodiversity;[7] these puzzles are examples from the biological literature[8] in which the complexities of the ideas within biodiversity are discussed. The focus here will be on the *scientific* puzzles within the concept of biodiversity, though in some instances it is difficult to separate science from ethics, aesthetics, and religion.[9] Lawmakers may not be qualified to solve these puzzles from a scientific perspective, but they need to take them into account.

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[4] *See* Federal Water Pollution Control Act, 33 U.S.C. § 1251(a)(1) (2000); Weyerhaeuser Co. v. Costle, 590 F.2d 1011, 1025 (D.C. Cir. 1978) (describing § 1251's goal of pollutant discharge elimination as "monumental" and an "aspiring goal").

[5] *E.g.*, National Environmental Policy Act of 1969, 42 U.S.C. § 4332 (2000); James T.B. Tripp & Nathan G. Alley, *Streamlining NEPA's Environmental Review Process: Suggestions For Agency Reform*, 12 N.Y.U. ENVTL. L.J. 74, 85 (2003) ("Due in part to the unwillingness of the courts to read more substantive requirements into NEPA, agencies are not bound by the alternatives analyses that result from preparation of an [environmental impact statement].").

[6] *Infra* Part I.

[7] *Infra* Part II.

[8] I do not claim to have been the original discoverer of any of these biological puzzles, each of which is being written about extensively in the biological literature, but only a few have been addressed in the legal literature.

[9] A wide range of arguments for protecting biodiversity have been marshaled, including economic, religious, ethical, and aesthetic arguments. DAVID TAKACS, THE IDEA OF BIODIVERSITY: PHILOSOPHIES OF PARADISE 194-287 (1996). A good summary of these arguments is found in Holly Doremus, *Patching the Ark: Improving Legal Protection of Biological Diversity*, 18 ECOLOGY L. Q. 265, 269-81 (1991) [hereinafter *Biological Diversity*]; *see also* Holly Doremus, *Listing Decisions under the Endangered Species Act: Why Better Science Isn't Always Better Policy*, 75 WASH. U. L.Q. 1029, 1134-38 (1997) [hereinafter *Endangered Species*] (arguing that listing of endangered species should not be based solely on scientific criteria). It is not my intent to downplay the importance of these arguments, but the biological puzzles are complex enough to support my thesis.

Thirteen puzzles are identified in this Article:

1. To what extent does a lack of genetic variability itself threaten a species or population's existence? How much should genetic variability be protected?

2. Should we protect phenotypic diversity, or plasticity of species, which enables species to adapt to future environmental change?

3. Can scientific criteria be developed for designating focal species to serve as proxies for biodiversity?

4. Should we treat species differently depending on the extent to which they have an evolutionary history or hidden traits that are similar to other species?

5. Should we give priority to locally endemic species and lesser protection to peripheral populations of species that interact with abundant populations of the same species living outside the United States?

6. Should we continue to utilize the traditional concept of species to determine species richness and species endangerment, or should we switch to newer systems of classifying organisms that emphasize similarity of genetic lineage?

7. Where two or more species appear to perform the same ecological function, should we focus more on ensuring that the function is performed, or on the protection of each individual species?

8. What criteria should be used to decide whether a species of plant or animal has an adverse effect on biodiversity because it arrived at its present location by the wrong method or at the wrong time? What should "wrong" mean in this context?

9. What criteria should decide whether a hybrid species has a positive or adverse effect on biodiversity? When should the potential to create new hybrid species be considered an addition or threat to biodiversity?

10. Do we need to give special priority to those species that are likely to have difficulty in dispersing to appropriate habitats in response to environmental change?

11. Should we encourage *all* increases in biodiversity that result from natural selection, even though this may include resistant antibiotics or pesticides, or should we only emphasize protection of the biodiversity of *existing* species?

12. Should we protect groups of organisms that result from

captive breeding or bioengineering in the same way that we protect groups of "natural" origin?

13. Should we try to maintain existing biodiversity or to promote new mixtures of species that can better adapt to continuing environmental change?

I am not by any means suggesting that scientific issues are the only concerns that should be considered in drafting environmental legislation.[10] Many commentators have pointed out that there are valuable ethical, aesthetic, philosophical, religious, psychological (and undoubtedly still other) perspectives on biodiversity, not to mention the political and economic issues that lawmakers typically face.[11] However, the concept of biodiversity is easily (mis)perceived as having a single, definitive scientific meaning, while in the end its feasibility as a legal standard will stand or fall on its scientific content, which often is neither single nor definitive. By only discussing biological puzzles here, I am merely trying to limit the Article to a workable format and not trying to disparage issues drawn from other fields.

The Article also excludes issues on which scientists may disagree about policy or strategy but not about the scientific merits. For example, scientists might argue about whether a legal definition of biodiversity should include the idea of diversity among ecosystems. Some might argue that a concentration on the protection of ecosystems is the best way to protect biodiversity.[12]

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[10] As Alyson Flournoy correctly emphasizes, it is important to counteract the tendency to treat environmental problems as purely technical or political. "Environmental law is itself an important expression of social value." Alyson C. Flournoy, *In Search of an Environmental Ethic*, 28 COLUM. J. ENVTL. L. 63, 114 (2003). *See also* Doremus, *Endangered Species*, *supra* note 9, at 1134-38.

[11] *See, e.g.*, STEPHEN R. KELLERT, THE VALUE OF LIFE: BIOLOGICAL DIVERSITY AND HUMAN SOCIETY 10-20 (1996). Even biologists themselves have been known to base their support for biodiversity protection on grounds that are more ethical than scientific. *See* LAWRENCE B. SLOBODKIN, A CITIZEN'S GUIDE TO ECOLOGY 139 (2003). *See also* Doremus, *Biological Diversity*, *supra* note 9, at 269-81.

[12] Some definitions of biodiversity also include variety of ecosystems as an essential element, as in the Convention on Biological Diversity. SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY, HANDBOOK OF THE CONVENTION OF BIOLOGICAL DIVERSITY 5 (2001). The United States is not a party to the Convention on Biological Diversity because Congress has not ratified the agreement. *See* SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY, UNITED NATIONS ENV'T PROGRAMME, PARTIES TO THE CONVENTION ON BIOLOGICAL DIVERSITY, *at* http://www.biodiv.org/world/parties.asp (last updated Feb. 13, 2004).

Other scientists might counter that the idea of an ecosystem is simply the aggregation of the organisms that are adapted to a particular physical environment defined by the observer, and the protection of the organisms themselves is the only scientifically definable concept.[13] They would not be disagreeing on the importance of protecting biodiversity, but only on an issue of strategy. This is an important issue, but I do not treat it as the kind of *scientific* puzzle discussed in this Article.

Another strategic debate involves the issue of whether biodiversity should be characterized only by the existence of different kinds of organisms, or whether it should also emphasize the need for the presence of a certain optimum number of each kind of organism. Again, scientists may disagree about the wisdom of including such a policy as a practical matter and would certainly have trouble agreeing on specific numbers, but I do not sense any disagreement with the idea that biodiversity means more than simply maintaining hopeless remnants of species.[14]

Despite limiting the Article to biological issues over which there is disagreement by scientists on the scientific merits of the

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[13] Eminent scientists have pointed to the fuzziness of the definition of the ecosystem. *See* Robert V. O'Neill, *Is it Time to Bury the Ecosystem Concept? (With Full Military Honors, of Course!)*, 82 ECOLOGY 3275, 3279 (2001); S. T. A. Pickett & M. L. Cadenasso, *The Ecosystem as a Multidimensional Concept: Meaning, Model and Metaphor*, 5 ECOSYSTEMS 1 (2002); DAN L. PERLMAN & GLENN ADELSON, BIODIVERSITY: EXPLORING VALUES AND PRIORITIES IN CONSERVATION 9-10 (1997) (noting the "conceptual difficulties inherent in the constituent terms of biodiversity (namely, genes, species, and ecosystems)."). As U.C. Davis Law Professor Holly Doremus puts it, "We struggle to define ecosystems and biodiversity, or thresholds of unacceptable harm to either, with sufficient precision to constrain a reluctant or overzealous agency." Holly Doremus, *Biodiversity and the Challenge of Saving the Ordinary*, 38 IDAHO L. REV. 325, 347 (2002). *See also* Ian R. Swingland, *Biodiversity, Definition of*, *in* 1 ENCYCLOPEDIA OF BIODIVERSITY 377, 381 (Simon A. Levin ed., 2001) ("[I]t is difficult to make a quantitative assessment of biodiversity at the ecosystem, habitat or community level."). I have discussed the apparent decline in the scientific use of the term "ecosystem" elsewhere. Fred Bosselman, *What Lawmakers Can Learn from Large-Scale Ecology*, 17 J. LAND USE & ENVTL L. 207, 222-28 (2002). If the legal definition of biodiversity is expanded to include ecosystem variety, a wide range of additional scientific puzzles would need to be addressed.

[14] This issue is addressed very well in Holly Doremus, *Restoring Endangered Species: The Importance of Being Wild*, 23 HARV. ENVTL. L. REV. 1, 11-12 (1999) (noting fundamentally different selection pressures that bear on specimens in captivity, which select distinctly different traits than wild specimens).

issue, this Article has grown lengthy. I have tried to include many citations to the biological literature to help readers to form their own judgment on these issues, but be warned that these citations are only a small sample of the vast biological literature, which makes a library of law reviews look very modest.

Part I briefly surveys the history of the concept of biodiversity and outlines the challenges posed by its current use in lawmaking. Part II engages with the biological literature to outline important puzzles in the concept of biodiversity. Part III offers a few tentative ideas about the way the law might deal with some of these puzzles. The law is accustomed to living with scientific puzzles, and those addressed in this Article are no more complex than many of the biochemical issues that environmental law has continually struggled with. Scientists are constantly improving our environmental knowledge base, but there is still a high degree of uncertainty. As Daniel Farber has noted, "[c]hange has been a constant theme in environmental law."[15] These puzzles are only more dangerous if they remain hidden.

## I
## BIODIVERSITY: A BRIEF HISTORY & CURRENT CHALLENGES

The word biodiversity, as a shorthand term for biological diversity,[16] was invented for a joint National Academy of Sciences-Smithsonian Institution forum on biological diversity in 1986.[17] The 1990 edition of the *New Penguin Dictionary of Biology* did not even include the term.[18] Today, the term biodiversity is in widespread public use, often in the sense of a

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[15] DANIEL A. FARBER, ECO-PRAGMATISM: MAKING SENSIBLE DECISIONS IN AN UNCERTAIN WORLD 178 (1999).

[16] It is clear that the terms "biological diversity" and "biodiversity" may be used as synonyms without inaccuracy. For a discussion of the terms' interchangeable nature, see John L. Harper & David L. Hawksworth, *Preface*, *in* BIODIVERSITY: MEASUREMENT AND ESTIMATION 6 (D. L. Hawksworth ed., 1995).

[17] TAKACS, *supra* note 9 at 36-39. The papers from the forum appear in BIODIVERSITY (Edward O. Wilson ed., 1988). Usage of the term "biological diversity" apparently goes back only to about 1980. Harper & Hawksworth, *supra* note 16, at 6.

[18] NEW PENGUIN DICTIONARY OF BIOLOGY (8th ed. 1990). *See also* OXFORD DICTIONARY OF BIOLOGY 70 (4th ed. 2000) (extensively defining biodiversity as including species diversity, ecological diversity and genetic diversity).

measurement of the number of different species in a given area,[19] although most scientists include measures of diversity within species as well.[20]

Science historian David Takacs has devoted an entire book to a carefully researched analysis of the history and meaning of the term biodiversity.[21] In the course of his research he interviewed and reported verbatim the views of twenty-three leading biologists and read a great deal of the available literature.[22] Biodiversity, he concludes, "lies at the heart of a complex web; strands radiate outward, taut with tensions"; biologists' "factual, political, emotional, aesthetic, ethical, and spiritual feelings about the natural world are embodied in the concept of *biodiversity*; so packaged, *biodiversity* is used to shape public perceptions of, feelings about, and actions toward that world."[23]

By pointing out the use of the term in public relations, Takacs is not trying to disparage the topic's importance, nor am I. A certain degree of oversimplification is necessary to convey complex ideas to the general public, and the term has well served

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[19] *See, e.g.*, COMM. ON NONECON. AND ECON. VALUE OF BIODIVERSITY, NAT'L RESEARCH COUNCIL, PERSPECTIVES ON BIODIVERSITY: VALUING ITS ROLE IN AN EVERCHANGING WORLD 20, 23 (1999) (equating, in part, biodiversity with the number and novelty of the species present); Mollie Beattie, *Biodiversity Policy and Ecosystem Management*, *in* BIODIVERSITY AND THE LAW 11, 13-15 (William J. Snape ed., 1996) (defending the change in emphasis on the part of the United States Fish and Wildlife Service's administration of the Endangered Species A from protection of single species to protection of ecosystems); Bryan G. Norton, *On the Inherent Danger of Undervaluing Species*, *in* THE PRESERVATION OF SPECIES 110, 111 (Bryan G. Norton ed., 1986) ("Species diversity is necessary, but not sufficient, for complexity."). A 1997 survey of both scientific journals and journals of general public interest found that "diversity" and "biodiversity," when used in scientific journals, were usually clearly defined and included diverse entities in addition to species, but when these terms were used in other media they were not defined and appeared to refer only to number of species. Dean C. Adams et al., *An "Audience Effect" for Ecological Terminology: Use and Abuse of Jargon*, 80 OIKOS 632, 634 (1997).

[20] *E.g.*, NAT'L RESEARCH COUNCIL, *supra* note 19, at 22-23 (stating that "[g]enetic diversity provides an economic basis for protecting and conserving biodiversity," and noting that the existence of geographic variations within a species has practical implications for biodiversity managers).

[21] *See generally* TAKACS, *supra* note 9.

[22] *Id.*, at xiii.

[23] *Id.*, at 2. *See also* Alexej Ghilarov, *What Does 'Biodiversity' Mean: Scientific Problem or Convenient Myth?*, 11 REV. ECOLOGY & EVOLUTION 304 (1996) (suggesting that biodiversity is a "useful fad that helps many ecologists to survive doing science.").

the purpose of alerting the public to serious issues. Today, the issue of biodiversity is big news; during the week of May 3, 2003, a week selected at random, the Nexis database of "newspapers" listed 138 articles containing references to biodiversity or biological diversity. From the early grades, children are being taught that biodiversity is an important issue,[24] and only a few skeptics challenge the importance of biodiversity.[25] Such widespread acceptance has potential drawbacks, as J. B. Ruhl has pointed out; the use of biodiversity as a slogan to justify whatever policy one wants to advance will damage scientific credibility.[26]

My real concern is that, although only two decades old, the term biodiversity has begun to appear in the lawmaking process. An examination of recent statutes and regulations and the Federal Register suggests that biodiversity (or its synonym biological diversity) is beginning to be used in a wide variety of contexts. In some recent statutes, biodiversity is quite appropriately described as a subject to be researched.[27] In other recent statutes, the

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[24] *See, e.g.*, EDWARD O. WILSON & DAN L. PERLMAN, CONSERVING EARTH'S BIODIVERSITY (Island Press CD-ROM, 2001) (educational material prepared for use in schools); WORLD WILDLIFE FUND, BIODIVERSITY 911 ON THE WEB (informational and "fun and games" site for kids, focusing on biodiversity issues), *at* http://www.biodiversity911.org (last visited Feb. 28, 2004). *But see* Doremus, *supra* note 13, at 339 (noting that biodiversity is more abstract than place-specific environmental advocacy, it "doesn't make a good poster or soundbite; it doesn't get anyone's blood racing.")

[25] *See* ALLAN K. FITZSIMMONS, DEFENDING ILLUSIONS: FEDERAL PROTECTION OF ECOSYSTEMS 91 (1999) ("If the standard that we use to judge the quality of the American environment . . . gets beyond romanticism . . . then you must conclude that overall conditions are good and getting better."); BJØRN LOMBORG, THE SKEPTICAL ENVIRONMENTALIST: MEASURING THE REAL STATE OF THE WORLD 253-56 (2001) (criticizing exaggerated claims of the number of extinct species). *But see* PAUL R. GROSS & NORMAN LEVITT, HIGHER SUPERSTITION: THE ACADEMIC LEFT AND ITS QUARRELS WITH SCIENCE 159 (1994) (endorsing "unreservedly" the case for treating biodiversity as a problem of the first importance).

[26] 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, 568-69 (1995). *See also* Harper & Hawksworth, *supra* note 16, at 6 (explaining that if biodiversity means different things to different people, it is better to reveal and acknowledge the differences than to cause confusion); Alyson C. Flournoy, *Coping with Complexity*, 27 LOY. L.A. L. REV. 809, 823 (1994) ("Avoiding illusory [scientific] precision may improve regulators' accountability. This may help to improve public confidence and acceptance of regulatory decisions.").

[27] For example, the National Commission on Wildfire Disasters is mandated to study the effect of fires on the biodiversity of affected areas. Wildlife Disaster

protection or preservation of biodiversity is cited as one of the numerous purposes or justifications for a legal standard, but in such a way that seems unlikely to be interpreted as imposing specific enforceable obligations.[28] Although the direct impact of such usages is unimportant, these statutes illustrate the dangerous habit of simply adding biodiversity to any list of "green" values without a lot of thought.

More serious, however, is the use of biodiversity as an undefined legal standard. For example, the North American Agreement on Environmental Cooperation "shall also be implemented to advance . . . biodiversity preservation . . . ."[29] The U.S. Fish and Wildlife Service (FWS) must administer the Midway Atoll National Wildlife Refuge in a manner consistent with "maintaining and restoring natural biological diversity within the refuge."[30] Similar use of the term as a legal standard appears in recent federal agency regulations, such as the NMFS rule that management units for threatened salmon species must "maximize consideration of important biological diversity,"[31] the Department of Agriculture's recent organic food production standards that permit certain perennial cropping systems that "introduce biological diversity in lieu of crop rotation,"[32] and the Federal Highway Administration's wetland mitigation regulations that say

Recovery Act of 1989, Pub. L. No. 101-286, title I, § 103(a), 104 Stat. 172 (1990). The Institute for Tropical Forestry in Puerto Rico and the Institute of Pacific Islands Forestry conduct research on the effects of deforestation on biodiversity. 7 U.S.C. § 6706 (2000). The Secretary of Agriculture can make grants to study the effects of climate on biodiversity. Competitive, Special, and Facilities Research Grant Act, 7 U.S.C. § 450i(b)(2)(D) (2000).

28 *E.g.*, Agricultural Genome Initiative, 7 U.S.C. § 5924(b)(6) (2000) ("The Secretary of Agriculture . . . shall conduct a research initiative . . . for the purpose of . . . ensuring preservation of biodiversity to maintain access to genes that may be of importance in the future . . . ."); National Park of American Samoa, 16 U.S.C. § 410qq(a)(2) (2000) ("The Congress finds that . . . [t]he loss of these [tropical] forests leads to the extinction of species, lessening the world's biological diversity, [and] reduces the potential for new medicines and crops . . . .").

29 Exec. Order No. 12,915, 59 Fed. Reg. 25,775 (May 13, 1994), *reprinted in* 19 U.S.C. § 3472 app. at 700-01 (2000).

30 Exec. Order No. 13,022, 61 Fed. Reg. 56,875 (Oct. 31, 1996), 48 U.S.C. ch. 3 app. at 95-96 (2003). "Natural" merely opens another difficult issue. *See* discussion at notes 386-453 *infra*.

31 Anadromous fish, 50 C.F.R. § 223.203(b)(4)(i)(A) (2003).

32 Terms defined, 7 C.F.R. § 205.2 (2003).

that one of a wetland's functions must be to support biodiversity.[33] The intent behind these uses of biodiversity as a standard is undoubtedly honorable, but I hope that this Article will make it clear that the use of the term biodiversity as a standard, in the absence of a carefully detailed definition, creates a potential for litigation that could defeat the drafters' intention. As Holly Doremus insightfully highlights, the science of taxonomy offers "a virtually limitless arsenal of weapons with which to do battle."[34]

## II
## THE PUZZLES OF BIODIVERSITY

Biologists recognize that biodiversity is an inherently multidimensional idea that cannot be simplified into a single formula or number.[35] Princeton University biologist Simon A.

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[33] "Wetland or habitat functional capacity means the ability of a wetland to perform natural functions, such as provide wildlife habitat, [and] support biodiversity . . . ." Definitions, 23 C.F.R. § 777.2 (2002).

[34] Doremus, *Endangered Species*, *supra* note 9, at 1088 (quoting S. REP. NO. 96-151, at 14 (1979)). For a review of the use of the term biodiversity in state land use law, see Linda Breggin & Susan George, *Planning for Biodiversity: Sources of Authority in State Land Use Laws*, 81 VA. ENVTL. L.J. 81 (2003).

[35] Andy Purvis & Andy Hector, *Getting the Measure of Biodiversity*, 405 NATURE 212 (2000). To ecologists:

> biodiversity is a complex and multifaceted concept, and little is known about the ecological consequences of diversity per se. For example, how important is biodiversity to the stability and resilience of ecological communities and ecosystems? What aspects of biodiversity (for example, number of species, genetic variation, or architectural diversity) are most important to ecological systems? What hierarchical levels of biodiversity (for example, genes, genotypes, species, or community types) are most important to which ecological functions (for example, persistence of populations and communities, flux rates of nutrients, or global environmental change)? Because these questions remain largely unanswered, biological diversity requires much closer evaluation as a scientific target for conservation efforts.

Richard S. Ostfield et al., *Themes*, *in* THE ECOLOGICAL BASIS OF CONSERVATION: HETEROGENEITY, ECOSYSTEMS, AND BIODIVERSITY 123 (S.T.A. Pickett et al. eds., 1997). "Not only is there no single measure of biodiversity, but even when you have chosen which facet to quantify it is rarely possible to measure biodiversity in the way one might ideally like." KEVIN J. GASTON & JOHN I. SPICER, BIODIVERSITY: AN INTRODUCTION 6 (1998). Biodiversity is "often re-defined on each occasion according to the context and purpose of the author." Swingland, *supra* note 13, at 378. The National Science Foundation now likes to use the term "biocomplexity," which may more closely match the real intent of exploring the "interactivity of biota and the environment." *E.g.*, WORKING GROUP ON ENVTL. RESEARCH AND EDUC., NAT'L SCI. FOUND., FUNDING

Levin points out that biodiversity is a "picture whose intricacies defy simple description."[36]

Biodiversity does not refer to a single number, though discussion of it usually begins with species counts.[37] Equally important, however, is the diversity of populations within a species, the diversity of species within a functional group, and the diversity of functional groups within an ecosystem.[38] Furthermore, as Levin states, "species themselves are not monolithic collections of indistinguishable units; genetic and demographic diversity within populations play a vital role in establishing the resiliency of ecosystems and their ability to continue to provide the goods and services we rely on."[39]

There are many situations in which different dimensions of biodiversity suggest different applications to problems in the field, so that a resource manager forced to maximize biodiversity might have to choose among a variety of alternatives, each of which will promote some aspect of biodiversity but impact others adversely.[40] Various examples of this problem will be discussed in the text to illustrate some of the more interesting puzzles inherent in the application of the idea of biodiversity to actual landscapes. The puzzles are summarized at the appropriate places in the text that follows.

### A. *Measuring Biodiversity: Gene, Phenotype, Species, Lineage or Function?*

Although the most popular usage of the term biodiversity usually refers simply to the number of different species in an area (biologists call this "species richness" or "alpha diversity"[41]),

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OPPORTUNITIES, BIOCOMPLEXITY IN THE ENVIRONMENT, *at* http://www.nsf.gov/geo/ere/ereweb/fund-biocomplex.cfm (last updated Feb. 20, 2004). The term is used for large scale, multidisciplinary studies that are relevant to a wide range of organisms and environments. William K. Michener et al., *Defining and Unraveling Biocomplexity*, 51 BIOSCIENCE 1018, 1019-20 (2001).

36 Simon A. Levin, FRAGILE DOMINION: COMPLEXITY AND THE COMMONS 77 (1999).

37 NAT'L RESEARCH COUNCIL, *supra* note 19, at 23-24.

38 *See id*.

39 LEVIN, *supra* note 36, at 76-77.

40 *See* NAT'L RESEARCH COUNCIL, *supra* note 19, at 22-23.

41 *Id*. "Beta diversity" refers to the differences between sites; "gamma diversity" is sometimes used to describe differences between continents or other very large areas. BRIAN GROOMBRIDGE & MARTIN D. JENKINS, WORLD ATLAS

scientists typically use the term biodiversity to include a wider range of diversity.[42] Scientists use various definitions, but the most concise and generic is the one used by the National Research Council in its report, *Perspectives on Biodiversity*: "the variety and variability of biological organisms."[43] Biologists analyze variability of organisms at different levels, all of which are arguably biodiversity, and each of which will be discussed in turn:

> (1) variations in the genetic composition of organisms;
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> (2) variations in the appearance ("phenotype") of organisms;
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> (3) variations among taxonomic categories of organisms, such as species;
>
> (4) variations in the evolutionary lineage of organisms; and
>
> (5) variations in the ecological function the organisms perform.[44]

1. *Is genetic variability important?*

The science of genetics is only about a century old.[45] As the science has developed–at first gradually and now at a bewilderingly rapid pace–the attitudes of scientists toward genetic variability have gone through stages. Initially, a high degree of variability was called "genetic load," a term that clearly connoted the undesirability of such a condition.[46] As humans bred plants and animals, however, they found that too little genetic variability often resulted in lack of fitness, a phenomenon they characterized

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OF BIODIVERSITY: EARTH'S LIVING RESOURCES IN THE 21[ST] CENTURY 78 (2002).

42 TAKACS, *supra* note 9, at 51 (noting breadth of published definitions of biodiversity). "Biodiversity is, in simple terms, a catchall for describing levels of being biologically different or variable." J. L. Gittleman et al., *Detecting Ecological Pattern in Phylogenies*, *in* BIODIVERSITY DYNAMICS: TURNOVER OF POPULATIONS, TAXA, AND COMMUNITIES 51 (Michael L. McKinney & James A. Drake eds., 1998).

43 NAT'L RESEARCH COUNCIL, *supra* note 19, at 20; *see also id*. at 29-30 (variety and variability of organisms can be achieved only by providing a wide range of ecological communities).

44 *See* Ostfield et al., *supra* note 35, at 123.

45 Although Gregor Mendel performed the key experiments in the 1860s that led to the development of genetic science, these experiments were largely ignored until they were rediscovered around the beginning of the twentieth century. ERNST MAYR, EVOLUTION AND THE DIVERSITY OF LIFE 329-53 (1976).

46 *See infra* Part II.A.1.a.

as "inbreeding depression."[47] In response, scientists concluded that in many instances a high degree of genetic variability enhanced a species' adaptability to changing environments, making such variability a highly desirable trait. Today, however, increased awareness of many "natural clones" has led many scientists to doubt the universality of the assumption that genetic variability is necessary to survival.[48] At the level of resource management, the importance of genetic variability continues to be widely debated.[49]

a. *Genetic load*

Early evolutionary biologists incorporated new awareness of genetics into an assumption that, if populations of a species were large enough, the gradual process of evolution would eventually eliminate a lot of the species' genes, because if the species was successful in adapting to the environment it would no longer need the extraneous genes; biologists described the genes that were assumed to be surplus as "genetic load."[50] In other words, they believed that the fitness of any organism would be increased if it concentrated its energy on the genes that were immediately useful; this "fitness preference theory" postulated that over time the characteristics that adapted to the best fit with their environment would survive and the others would disappear.[51]

Given this assumption of fitness preference, scientists were originally puzzled at the wide range of apparently extraneous genetic material that seemed to have escaped this evolutionary process.[52] As one researcher put it:

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[47] *See infra* Part II.A.1.b.

[48] *See infra* Part II.A.1.d.

[49] *See infra* Part II.A.1.e.

[50] DAVID J. MERRELL, THE ADAPTIVE SEASCAPE: THE MECHANISM OF EVOLUTION 60-61 (1994). For a history of the idea of genetic load, see BRUCE WALLACE, FIFTY YEARS OF GENETIC LOAD: AN ODYSSEY (1991). *See also* Theodosius Dobzhansky, *Genetic Loads in Natural Populations*, 126 SCI. 191 (1957) (describing the concept of genetic load in terms of the assumption that most mutations are harmful to an organism).

[51] GEORGE GAYLORD SIMPSON, THE MEANING OF EVOLUTION 275-79 (1949); MAYR, *supra* note 45, at 44-52.

[52] *See* Dobzhansky, *supra* note 50, at 192; Eviatar Nevo, *Genetic Diversity in Nature: Patterns and Theory*, 23 EVOLUTIONARY BIOLOGY 217, 218, 241 (1988) (noting that "neither the biochemical and physiological nor the DNA studies *to date* can independently solve the general problem of the significance of genetic diversity in nature," presenting "inferential evidence" that heterogeneity of an

> [t]he study of genetic variation in natural populations had one consistent result: the amount of variation revealed always seemed to be far greater than most workers expected. The preconception of a species composed of a number of phenotypically and genetically similar individuals was gradually eroded to the point where a new paradigm had to be sought. Not only genic but chromosomal polymorphism was rampant.[53]

It was assumed that the genetic load was hampering the fitness of those organisms that were carrying it.[54]

b. *Inbreeding depression*

The concept of genetic load did not survive completely intact, however, as scientists soon recognized that healthy organisms required a certain degree of genetic variability,[55] and that inbreeding within small populations could increase the prevalence of unhealthy traits.[56] This condition became known as "inbreeding depression."[57]

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environment is a major factor influencing genetic diversity in populations, and urgently calling for more direct study of these issues).

[53] MERRELL, *supra* note 50, at 75. *See also* DAVID J. DEPEW & BRUCE H. WEBER, EVOLUTION AT A CROSSROADS: THE NEW BIOLOGY AND THE NEW PHILOSOPHY OF SCIENCE, 247-53 (1985); ERNST MAYR, ONE LONG ARGUMENT: CHARLES DARWIN AND THE GENESIS OF MODERN EVOLUTIONARY THOUGHT 152-53 (1991).

[54] For further discussion of this debate, see STEPHEN JAY GOULD, EIGHT LITTLE PIGGIES: REFLECTIONS IN NATURAL HISTORY 396-406 (1993). Similar reasoning led to various schemes to eliminate "deviant genes" in humans. *See, e.g.*, R. C. LEWONTIN ET AL., NOT IN OUR GENES: BIOLOGY, IDEOLOGY AND HUMAN NATURE 168-73 (1984). Two recent books of general interest have explored in a readable way the history of human manipulation of the genetic makeup of other organisms through plant and animal breeding. MICHAEL POLLAN, THE BOTANY OF DESIRE: A PLANT'S-EYE VIEW OF THE WORLD (2001); SUE HUBBELL, SHRINKING THE CAT: GENETIC ENGINEERING BEFORE WE KNEW ABOUT GENES (2001).

[55] *See* MERRELL, *supra* note 50, at 75 ("[G]enetic load is a concept whose time as come, and gone."); MICHAEL RUSE, PHILOSOPHY OF BIOLOGY TODAY 29 (1988) (noting vindication of the theory that there is a great deal of natural genetic variation in all organisms); Gábor Vida, *Genetics and Conservation Biology*, *in* CONSERVATION GENETICS 9, 14 (V. Loeschcke et al. eds., 1994) ("[D]epleted genetic diversity makes GMOs very susceptible to an epidemic disaster."). *See also* NAT'L RESEARCH COUNCIL, GRAND CHALLENGES IN THE ENVIRONMENTAL SCIENCES 23 (2001) (stating that genetic diversity is a "powerful influence on ecological success," although we lack a comprehensive theory that would allow quantification of the effect).

[56] For a helpful discussion of the various meanings of "inbreeding," see A. R.

Studies of the genetic characteristics of small populations of organisms have often found that inbreeding depression appears to increase the mortality of inbred offspring.[58] For example, a recent thirteen-year study of a rare South American monkey, the golden lion tamarin, found that the low survival rate of inbred tamarins may be a significant problem for the smaller populations of the species, which is restricted to some fourteen forest fragments of various size in Brazil.[59] This concern about the effects of inbreeding depression led to the general premise that (in stark contrast to the prior notion of genetic load) too little genetic variability was a major cause of lack of fitness in both animals[60] and plants.[61]

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Templeton & B. Read, *Inbreeding: One Word, Several Meanings, Much Confusion*, *in* CONSERVATION GENETICS 91 (V. Loeschcke et al. eds., 1994) (noting three meanings of inbreeding: 1. measure of shared ancestry; 2. genetic drift in a finite population; and 3. a system of mating in a reproducing population).

[57] *See* Philip W. Hedrick & Steven T. Kalinowski, *Inbreeding Depression in Conservation Biology*, 31 ANN. REV. ECOLOGICAL SYS. 139 (2000); RICHARD FRANKHAM ET AL., INTRODUCTION TO CONSERVATION GENETICS 280-308 (2002). A similar phenomenon occurred in wild populations; if the size of the population were small, the frequency of particular genes and chromosomes might be altered (adversely or otherwise) simply by the laws of chance—a phenomenon known as "genetic drift." EDWARD O. WILSON, THE DIVERSITY OF LIFE 81-84 (1992).

[58] *See, e.g.*, Ilik Saccheri, *Inbreeding and Extinction in a Butterfly Metapopulation*, 392 NATURE 491 (1998); William B. Sherwin & Craig Moritz, *Managing and Monitoring Genetic Erosion*, *in* GENETICS, DEMOGRAPHY AND VIABILITY OF FRAGMENTED POPULATIONS 9, 14 (Andrew G. Young & Geoffrey M. Clarke, eds., 2000). Harmful levels of inbreeding have been found in some small populations of rare species in the wild, such as the Florida panther. E. Darrell Land & Robert C. Lacy, *Introgression Level Achieved through Florida Panther Genetic Restoration*, 17 ENDANGERED SPECIES UPDATE 100 (2000). Restoration of habitat has sometimes reduced genetic diversity and reduced reproductive potential of plants if the transplanted plants are too similar in genetic character. Susan L. Williams, *Reduced Genetic Diversity in Eelgrass Transplantations Affects Both Population Growth and Individual Fitness*, 11 ECOLOGICAL APPLICATIONS 1472, 1482 (2001).

[59] James M. Dietz et al., *Demographic Evidence of Inbreeding Depression in Wild Golden Lion Tamarins*, *in* GENETICS, DEMOGRAPHY AND VIABILITY OF FRAGMENTED POPULATIONS 203, 203-11 (Andrew G. Young & Geoffrey M. Clarke eds., 2000). For a discussion of the captive breeding program developed by a network of zoos to replenish the tamarin populations, see SALLY TONGREN, TO KEEP THEM ALIVE: WILD ANIMAL BREEDING 24-35 (1985). *See also* Andrew G. Young & Geoffrey M. Clarke, *Conclusions and Future Directions*, *in* GENETICS, DEMOGRAPHY AND VIABILITY OF FRAGMENTED POPULATIONS 361, 363-65 (Andrew G. Young & Geoffrey M. Clarke eds., 2000); Cynthia Graber, *Jewels of the Jungle*, WILDLIFE CONSERVATION, Jul.-Aug. 2003, at 34.

[60] *See generally* STEVE JONES, THE LANGUAGE OF THE GENES 107-08 (1993)

c. *Genetics and adaptability*

Biologists also came to agree with both the inbreeding depression theory and its converse; not only was lack of genetic variability bad, but the presence of a significant amount of genetic variety was good because of the continuing need to be able to adjust to future environmental change.[62] In other words, evolution was recognized as, in part, a reaction to environmental change[63] and, in turn, the cause of future environmental change.[64] As the Hungarian geneticist Gábor Vida put it:

> Evolution is a fascinating process which remembers every success, but forgets all failures. A suitable amount of genetic

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(discussing the adverse impact of inbreeding in humans as well as other animals).

[61] *See, e.g.*, Jonathan Silvertown et al., *Ecological and Genetic Correlates of Long-Term Population Trends in the Park Grass Experiment*, 160 AM. NATURALIST 409, 417 (2002) (stating that inbred grass species are less persistent than more genetically diverse species).

[62] NAT'L RESEARCH COUNCIL *supra* note 19, at 23 ("Current adaptations are important, but genetic diversity is also critical for the future resilience and persistence of natural systems. Variation is important to maintain a population's ability to respond to changing environmental conditions, whether natural or anthropogenic."); Robert M. May, *Conceptual Aspects of the Quantification of the Extent of Biological Diversity*, *in* BIODIVERSITY: MEASUREMENT AND ESTIMATION 13 (D.L. Hawksworth ed., 1995) ("[G]enetic variability enables a species to cope with old and new pathogens, environmental fluctuations, and so on."); David E. McCauley, *Effects of Population Dynamics on Genetics in Mosaic Landscapes*, *in* MOSAIC LANDSCAPES AND ECOLOGICAL PROCESSES 179, 183 (Lennart Hansson et al. eds., 1995) (suggesting that lack of genetic diversity reduces evolutionary potential and may threaten population viability). For example, bees having high genetic diversity are better able to withstand parasites. CARL ZIMMER, PARASITE REX: INSIDE THE BIZARRE WORLD OF NATURE'S MOST DANGEROUS CREATURES 175-76 (2000).

[63] *See, e.g.*, PETER R. GRANT, ECOLOGY AND EVOLUTION OF DARWIN'S FINCHES 435 (2d ed., 1999) (explaining that finches on Galapagos diversified in response to climatically driven changes in environmental conditions); LEVIN, *supra* note 39, at 128 ("Environmental change is constantly shifting the background against which selection is taking place; thus, adaptation occurs on a landscape that is in a perpetual state of oscillation, with peaks dissolving into valleys and new peaks arising from former valleys."). Some research suggests that behavior patterns and ecological adaptations of animals evolve more rapidly than morphological traits such as body weight, or life history traits such as length of gestation. Gittleman et al., *supra* note 42, at 51, 59-60.

[64] John N. Thompson et al., *Frontiers of Ecology*, 51 BIOSCIENCE 15, 20 (2001) ("As each organism responds to its environment in a manner prescribed by its genome and the specifics of its biophysical and biotic environment, it simultaneously modifies that environment."). *See also* DANIEL R. BROOKS & E. O. WILEY, EVOLUTION AS ENTROPY: TOWARD A UNIFIED THEORY OF BIOLOGY 48-49 (2d ed. 1988) (noting that organisms have profound effects on the shaping of their own abiotic environment).

> diversity might be such a success. Uniformity can be superior in some particular environment, but it is condemned to extinction in a changing world.[65]

Modern research at the molecular level increasingly confirms that genetic variability tends to be substantially greater than might have been predicted by a narrowly defined application of fitness preference theory,[66] and that this high degree of genetic diversity is a reaction to environmental heterogeneity over time. For example, recent studies of archaebacteria living in the near-boiling water of a particular Yellowstone hot spring have found much greater genetic variation among individuals and species than would have been anticipated in such an extreme environment.[67]

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[65] Vida, *supra* note 55, at 10. *See also* Eviatar Nevo, *Genetic Diversity*, *in* 3 ENCYCLOPEDIA OF BIODIVERSITY 195, 210 (Simon A. Levin ed., 2001) ("Environmental variability enhances genetic diversity. Natural selection appears to be a major driving evolutionary force maintaining genetic diversity in nature.").

[66] Nevo, *supra* note 67, at 195. As Simon Levin puts it:

> Organisms are constantly challenged by environmental uncertainty but have evolved a remarkable diversity of mechanisms to reduce it, or at least to minimize its consequences. These include behavioral and physiological plasticity; averaging mechanisms such as dispersal, dormancy, and iteroparity (multiple reproduction over a lifetime); and a variety of schemes for gaining information about the environment and learning to utilize it.

LEVIN, *supra* note 39, at 192. *See also* MERRELL, *supra* note 53, at 137-44. Some genetic research suggests that organisms actually perceive environmental change and mutate selectively as a way of adapting to the changes. David S. Thaler, *The Evolution of Genetic Intelligence*, 264 SCI. 224 (1994); Marina Chicurel, *Can Organisms Speed Their Own Evolution?*, 292 SCI. 1824 (2001). Increasing awareness of horizontal transfer of genes, not only among microorganisms but among plants, is adding new wrinkles to our understanding of evolution. Ulfar Bergthorsson et al., *Widespread Horizontal Transfer of Mitochondrial Genes in Flowering Plants*, 424 NATURE 197, 200 (2003) (suggesting we are only seeing the tip on the iceberg of horizontal gene transfer in plants).

[67] Mitchell L. Sogin & Gregory Hinkle, *Common Measures for Studies of Biodiversity: Molecular Phylogeny in the Eukaryotic Microbial World*, *in* BIODIVERSITY II: UNDERSTANDING AND PROTECTING OUR BIOLOGICAL RESOURCES 109, 119 (Marjorie L. Reaka-Kudla et al. eds., 1997). *See* DAVID A. WHARTON, LIFE AT THE LIMITS: ORGANISMS IN EXTREME ENVIRONMENTS 146-49 (2002) (explaining biological processes by which hyperthermophiles are able to survive). For theoretical analysis of the phenomenon of apparent overdiversification, see ROBERT WESSON, BEYOND NATURAL SELECTION 150-59 (1991). *See also* Rachel J. Whitaker et al., *Geographic Barriers Isolate Endemic Populations of Hyperthermophilic Archaaea*, 301 SCI. 976 (2003) (describing substantial genetic variety among isolated populations of hyperthermophilic microorganisms).

Field studies have also shown that the anticipated evolution toward genetic factors that maximize current fitness sometimes fails because of environmental change; for example, although increased birth weight of bird nestlings increases their chances of survival, birds react to times of food shortage by reducing birth weights.[68] Genetic diversity can help a population adapt to unpredictable environmental change because a population that contains a substantial degree of genetic variation will have the source material to allow natural selection to operate when environmental change takes place.[69] As organisms adapt and evolve, their genetic makeup changes, but the extent to which change is possible may depend on the variety of genetic material within the organism,[70] and the ability of the genetic material to change its pattern of regulation or to change the functions of the proteins the genes encode.[71]

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[68] J. Merilä et al., *Cryptic Evolution in a Wild Bird Population*, 412 NATURE 76 (2001) (noting that although higher birth weight contributes to current fitness of this species, trend is to lower birth weights as an adaptation to reduction in food supply).

[69] Michael Loreau et al., *Biodiversity and Ecosystem Functioning: Current Knowledge and Future Challenges*, 294 SCI. 804, 806 (1999) (noting that species that are functionally redundant at one time may not be redundant over longer time spans). Landscape level processes play an important role in maintaining genetic diversity. Jim Sanderson & Larry D. Harris, *The Re-Membered Landscape*, *in* LANDSCAPE ECOLOGY: A TOP-DOWN APPROACH 111 (Jim Sanderson & Larry D. Harris eds., 2000) ("Community gene pools differ according to the degree of landscape connectivity (a species-dependent parameter), the separation time, and quantifiable external factors . . . ."); Janis Antonovics et al., *Genetics and the Spatial Ecology of Species Interactions*, *in* SPATIAL ECOLOGY: THE ROLE OF SPACE IN POPULATION DYNAMICS AND INTERSPECIFIC INTERACTIONS 158, 178-79 (David Tilman & Peter Kareiva eds., 1997) (recognizing that regional dispersal is a key factor in genetic variation).

[70] May, *supra* note 50, at 13 (stating that the "genetic diversity within species is the raw stuff upon which evolutionary processes act."); RICK POTTS, HUMANITY'S DESCENT: THE CONSEQUENCES OF ECOLOGICAL INSTABILITY 226 (1996). *See also* NAT'L RESEARCH COUNCIL, *supra* note 19, at 21 (observing that evolution generates, sustains, shapes, and sometimes even diminishes biodiversity).

[71] John R. True & Sean B. Carroll, *Gene Co-option in Physiological and Morphological Evolution*, 18 ANN. REV. CELL DEV. BIOLOGY 53 (2002) ("Natural selection promotes evolutionary novelty by inventing new uses for the genetic toolkit.").

d. *Fitness and the natural clone*

Today, the pendulum may be starting to swing back from the orthodoxy that genetic diversity is an unqualified good; some biologists are questioning whether genetic variability is universally desirable. They point out that the emphasis on genetic variability originally came from scientists who were working with those categories of plants and animals that reproduce sexually—a category of organisms that has long dominated biological research.[72] With the development of microbiological technology[73] and the growing recognition of the importance of small organisms to both ecology and agriculture,[74] attention has begun to be focused on the proliferation of small organisms.[75] Microbiologists know that bacteria[76] are essential elements of most multicellular

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72 Paul V. Dunlap, *Microbial Diversity*, *in* 4 ENCYCLOPEDIA OF BIODIVERSITY 191, 195 (Simon A. Levin ed., 2001) (recognizing that academic bias against microbiology is only now beginning to be eliminated). For an interesting discussion of this dominance, see Lynn Margulis, *Kingdom Animalia: The Zoological Malaise from a Microbial Perspective*, *in* SLANTED TRUTHS: ESSAYS ON GAIA, SYMBIOSIS, AND EVOLUTION 91 (Lynn Margulis and Dorion Sagan eds., 1997).

73 NAT'L RESEARCH COUNCIL, *supra* note 55, at 25. For a description of the many technologies for measuring the diversity of microbes, see Kate M. Scow, *Microbial Biodiversity*, *Measurement of*, *in* 4 ENCYCLOPEDIA OF BIODIVERSITY 177, 180-89 (Simon A. Levin ed., 2001).

74 *See* WILLIAM H. SCHLESINGER, BIOCHEMISTRY: AN ANALYSIS OF GLOBAL CHANGE 189 (2d ed. 1997) (stating that most nutrients for land plants are supplied by biogeochemical transformations performed by fungi and bacteria in the soil). *See also* Frans A. A. M. deLeij et al., *Natural Investment in Diversity: The Role of Biological Communities in Soil*, *in* NATURE AND HUMAN SOCIETY: THE QUEST FOR A SUSTAINABLE WORLD 242, 243 (Peter H. Raven ed., 1997) (estimating that a gram of soil may contain thousands of different kinds of microbes); Rita R. Colwell, *Microbial Biodiversity and Biotechnology*, *in* BIODIVERSITY II: UNDERSTANDING AND PROTECTING OUR BIOLOGICAL RESOURCES 279, 281-285 (Marjorie L. Reaka-Kudla et al. eds., 1997).

75 Erko Stackebrandt, *Bacterial Biodiversity*, *in* 1 ENCYCLOPEDIA OF BIODIVERSITY 325, 326 (Simon A. Levin ed., 2001) (discussing that there is increasing awareness of the key role microorganisms play in ecological functions that benefit humans). *See generally* DAVID WARDLE, COMMUNITIES AND ECOSYSTEMS: LINKING THE ABOVEGROUND AND BELOWGROUND COMPONENTS (2002); Teri C. Balser et al., *Linking Soil Microbial Community Composition and Ecosystem Functioning*, *in* THE FUNCTIONAL CONSEQUENCES OF BIODIVERSITY: EMPIRICAL PROGRESS AND THEORETICAL EXTENSIONS 265 (Ann P. Kinzig et al. eds., 2001).

76 Current systems of taxonomic classification have divided what were formerly known as bacteria into two separate domains, the eubacteria and the archaea, because genetic analysis revealed that these two groups were only distantly related. The archaea include many of the "extremophiles"; i.e.,

living things. The ideas of Louis Pasteur, who thought all "germs" were the enemy, are passé—without the bacteria in our intestines, we would die.[77]

Many bacteria and other microorganisms reproduce asexually—their offspring are natural clones, genetically identical to their parent.[78] Nevertheless, the genetic diversity among bacteria is greater even than that among insects, which have long been noted for their genetic diversity.[79] The idea that a species is a group of organisms that can breed among themselves and produce fertile offspring[80] cannot be easily applied to most bacteria or other organisms that reproduce asexually.[81] Moreover, the early attempts to classify microbes based on their appearance when isolated in cultures produced results that show little resemblance to more recent studies based on DNA analysis.[82] Although it is

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microorganisms found in hot springs, deep sea vents, and other extreme conditions. Dunlap, *supra* note 72, at 199-202. *See also* CINDY LEE VAN DOVER, THE ECOLOGY OF DEEP-SEA HYDROTHERMAL VENTS (2000). Because the distinction does not seem important for purposes of my analysis, and because much of the scientific literature continues to refer to bacteria without making the distinction, I will do so in this Article as well.

[77] *See* TOM WAKEFORD, LIAISONS OF LIFE 108-10 (2001).

[78] Michael Travisano, *Bacterial Genetics*, *in* 1 ENCYCLOPEDIA OF BIODIVERSITY 348 (Simon A. Levin ed., 2001). *See also* Kevin de Queiroz, *The General Lineage Concept of Species and the Defining Properties of the Species Category*, *in* SPECIES: NEW INTERDISCIPLINARY ESSAYS 49, 79 (Robert A. Wilson ed., 1999) (stating that most species of organisms resemble slime molds and sponges more than they resemble tightly integrated multicellular organisms).

[79] Travisano, *supra* note 78, at 339.

[80] OXFORD DICTIONARY OF BIOLOGY, *supra* note 18, at 555. This and other concepts of species are discussed at more length at notes 277-353 *infra*.

[81] Travisano, *supra* note 78, at 340. *See also* M. Claire Horner-Devine et al., *An Ecological Perspective on Bacterial Biodiversity*, 271 PROCEEDINGS OF THE ROYAL SOCIETY, LONDON, Series B 113 (2004) (noting patterns emerging in bacterial diversity studies).

[82] Scow, *supra* note 73, at 178-79; Stackebrandt, *supra* note 75, at 325, 329-30, 336. Microbiologists are generally unhappy with early attempts to classify the organisms they study. *See, e.g.*, Anthony G. O'Donnell et al., *Theoretical and Practical Aspects of the Quantification of Biodiversity among Microorganisms*, *in* BIODIVERSITY: MEASUREMENT AND ESTIMATION 65, 66-67 (D.L. Hawksworth ed., 1995) (discussing strains of bacteria classified as different species have identical DNA sequences); Philippe Vandenkoornhuyse et al., *Extensive Fungal Diversity in Plant Roots*, 295 SCIENCE 2051 (2002) (stating that forty-nine separate fungus types were found on the roots of a single plant, only seven of which were closely similar to known types). *See also* David J. Patterson, *The Diversity of Eukaryotes*, 65 AM. NATURALIST S96 (1999) (proposing classification of hundreds of taxa of protists). For a readable introduction to a sample of microbial diversity, see JIM DEACON, THE MICROBIAL

known that genetic exchange among bacteria exists,[83] the evolutionary forces that cause high levels of diversity remain elusive.[84]

Microbes are not the only organisms that produce natural clones by reproducing asexually. Scientists have noted that some large and apparently prolific species of plants and animals are able to multiply in their natural environment without significant genetic variation.[85] Certain plants, such as the aspen, commonly multiply from the shoots of a common root system, so that a grove of trees may really be a single organism.[86] Common dandelions (talk about adaptability!) are often natural clones of a single parent because the dandelion has developed the ability to reproduce from seed asexually.[87]

In other cases, scientists have concluded that some phenomenon must be limiting genetic variety because they find genetically identical organisms in isolated locations; for example, studies have shown little genetic difference among groups of corals even after they have long been isolated.[88] This discovery of

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WORLD MICROORGANISMS AND MICROBIAL ACTIVITIES, *at* http://helios.bto.ed.ac.uk/bto/microbes (last visited March 3, 2004).

[83] Travisano, *supra* note 78, at 346-49.

[84] Nevo, *supra* note 65, at 195-96. Some point to the 3.5 billion year length of bacteria's evolution to explain the high diversity. Travisano, *supra* note 78, at 339.

[85] JOHN C. AVISE, GENETICS IN THE WILD 19-22 (2002); Steven V. Vollmer & Stephen R. Palumbi, *Hybridization and the Evolution of Reef Coral Diversity*, 296 SCI. 2023 (2002) (discussing how corals can multiply by cloning). The development of an organism from an unfertilized egg is known as parthenogenesis. OXFORD DICTIONARY OF BIOLOGY, *supra* note 18, at 440.

[86] For example, one aspen grove in Utah covers 107 acres and contains some 47,000 genetically identical trees. Bruce A. Stein et al., *A Remarkable Array: Species Diversity in the United States*, *in* PRECIOUS HERITAGE: THE STATUS OF BIODIVERSITY IN THE UNITED STATES 55, 56 (Bruce A. Stein et al. eds., 2000). This form of reproduction, known as "physiological integration," may provide fitness benefits, as measured by growth rate in plants. Peter Chesson & Andrew G. Peterson, *The Quantitative Assessment of the Benefits of Physiological Integration in Clonal Plants*, 4 EVOLUTIONARY ECOLOGY RES. 1153 (2002). Some mushrooms also spread underground and form immense organisms; one in Michigan covers forty acres and is estimated to weigh 100 tons. AVISE, *supra* note 85, at 174-75.

[87] MENNO SCHILTHUIZEN, FROGS, FLIES & DANDELIONS 30 (2001).

[88] Nancy Knowlton & Lee A. Weigt, *Species of Marine Invertebrates: A Comparison of the Biological and Phylogenetic Species Concepts*, *in* SPECIES: THE UNITS OF BIODIVERSITY 199, 202 (Michael F. Claridge et al. eds., 1997). Another example is a study that showed no negative effects of inbreeding in small, isolated squirrel populations despite lack of genetic variability. *See* Luc

identical genetic profiles, along with technological innovation, has helped lead to discussion of the possibility of cloning rare species as a conservation strategy,[89] although the inbreeding issue[90] would be significant for species that reproduce sexually.[91]

It is becoming increasingly likely that many organisms have a surprisingly good ability to adapt to changing environmental conditions without changing genetically, because a very small repertoire of genes, circuits and cellular events may be redeployed in different functional contexts to create highly different morphological structures.[92] This disconnect between rates of genetic change and rates of morphological change is a vexing problem for current scientific research.[93]

Today, ecological geneticists have rapidly increasing technological abilities to study adaptive evolution in populations of species in order to assess the ability of various species to respond to environmental change,[94] and in particular to the stress put on

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A. Wauters et al., *The Effects of Habitat Fragmentation on Demography and the Loss of Genetic Variation in the Red Squirrel*, 255 PROC. ROYAL SOC. LOND. B 107 (1994).

[89] Caroline P. Rogers, Note, *Solution or Stumbling Block?: Biological Engineering and the Modern Extinction Crisis*, 30 GA. J. INT'L & COMP. L. 141, 153-55 (2001).

[90] *See supra* Part II.A.1.b.

[91] Rogers, *supra* note 89, at 158-59.

[92] Neil H. Shubin & Charles R. Marshall, *Fossils, Genes, and the Origin of Novelty*, *in* DEEP TIME: PALEOBIOLOGY'S PERSPECTIVE 324, 330 (Douglas H. Erwin & Scott L. Wing eds., 2000). *See also* SCOTT CAMAZINE ET AL., SELF-ORGANIZATION IN BIOLOGICAL SYSTEMS 38 (2001) (noting that "the amount of information stored in . . . genes is much smaller than the amount of information needed to describe the structure of the adult individual.").

[93] *See* Jeffrey S. Levinton, *Evolution as Frozen Music*, 301 SCI. 768 (2003) (reviewing MARY JANE WEST-EBERHARD, DEVELOPMENTAL PLASTICITY AND EVOLUTION (2003)).

[94] Alan R. Templeton, *Biodiversity at the Molecular Genetic Level: Experiences from Disparate Microorganisms*, *in* BIODIVERSITY: MEASUREMENT AND ESTIMATION 59 (D. L. Hawksworth ed., 1995) ("Our ability to survey for genetic diversity at the molecular level has increased by orders of magnitude over the past few years."). *See also* Frank A. Bisby et al., *Characterization of Biodiversity*, *in* GLOBAL BIODIVERSITY ASSESSMENT 21, 63-70 (V. H. Heywood ed., 1995) (summarizing various methods of assessing genetic variation); Shubin & Marshall, *supra* note 92, at 337 ("Knowledge of genome structure, gene expression, and genome diversity is increasing exponentially, following dramatic technological progress. New methods for obtaining gene sequences, analyzing gene expression, and understanding gene function are generating new data faster than it can be analyzed.").

ecological systems by human activities.[95] Because it is impossible to know which particular traits of a population will be valuable as the environment changes, the National Research Council advocates the view that "[c]urrent adaptations are important, but genetic diversity is . . . critical for the *future* persistence and resilience of natural systems."[96]

e. *How relevant is genetic variability in practice?*

Despite all of this exciting research, scientists display a wide range of opinions about the practical importance of genetic variability. Some geneticists have downplayed the risk of inbreeding, and the subsequent weakness of the adaptive abilities of a population, as a cause of extinction.[97] These scientists suggest that, by the time that the population of a species gets small enough to be inbred, it is already at such serious risk from demographic factors that the genetic issues are irrelevant.[98] The risk that the entire population will be wiped out by disturbance or disease is much greater than the risks caused by inbreeding.[99]

Other biologists worry that an overemphasis on preserving genetic variability would work to the disadvantage of those species that have maximized current fitness, because any organism that

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[95] Leslie A. Real, *Current Directions in Ecological Genetics*, *in* ECOLOGICAL GENETICS xiii (Leslie A. Real ed., 1994). *See also* Alan R. Templeton, *Biodiversity at the Molecular Genetic Level: Experiences from Disparate Microorganisms*, *in* BIODIVERSITY: MEASUREMENT AND ESTIMATION 59 (D.L. Hawksworth ed., 1995) ("Without genetic diversity, a population cannot evolve and it cannot adapt to environmental change. Environmental change is now occurring on a global scale due to human activities, and many species will have to adapt to this change or experience an ever-increasing chance of extinction.").

[96] NAT'L RESEARCH COUNCIL, *supra* note 19, at 22-23 (emphasis added).

[97] *See* Kent E. Holsinger & Pati Vitt, *The Future of Conservation Biology: What's a Geneticist to Do?*, *in* THE ECOLOGICAL BASIS OF CONSERVATION: HETEROGENEITY, ECOSYSTEMS, AND BIODIVERSITY 202, 203 (Steward Pickett et al. eds., 1997); Templeton, *supra* note 82, at 61-63 (explaining that even a handful of organisms could carry over substantial amounts of genetic variability from an ancestral population); T. M. Caro and M. Karen Laurenson, *Ecological and Genetic Factors in Conservation: A Cautionary Tale*, 263 SCI. 485 (1994) (questioning popularly held belief that the cheetah's reproductive problems are genetic in origin).

[98] Kent E. Holsinger et al., *Genes, Demes and Plant Conservation*, *in* GENETICS AND THE EXTINCTION OF SPECIES 23, 24-25, 27 (Laura F. Landweber & Andrew P. Dobson eds., 1999).

[99] *See, e.g.*, Wauters et al., *supra* note 88, at 107 (stating that there are no detectable negative effects of inbreeding on small isolated squirrel populations despite lack of genetic variability).

maintains high genetic variability inevitably gives up some fitness to the current environment.[100] Some biologists believe that, even among sexually reproducing organisms, genetic variability enhances adaptation to environmental change only if the change is predictable, and that in unpredictable environments genetic variance reduces fitness.[101]

The issue is further complicated by the process of "coevolution," in which two or more different species evolve in reaction to each other. For example, evolutionary biologists have extensively studied the ways in which flowering plants have evolved in tandem with the insects and birds that pollinate them.[102] Parasitologists study how microbes and larger animals and plants join in unique adaptations to environmental conditions.[103] As scientists increase their awareness of the proliferation of mutualistic relationships among species, they become increasingly aware that the issue of genetic variability within a given species cannot be understood without also studying the other species with which it interacts.[104] Some genetic research suggests that the human genome may actually contain elements that were originally parts of independent bacteria but have now become incorporated in our genes.[105]

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[100] Russell Lande, *Extinction Risks from Anthropogenic, Ecological, and Genetic Factors*, *in* GENETICS AND THE EXTINCTION OF SPECIES 1, 14 (Laura F. Landweber & Andrew P. Dobson eds., 1999) (stating that "heritable variance in quantitative characters therefore imposes a fitness cost . . . on a population").

[101] David S. Woodruff, *Declines of Biomes and Biotas and the Future of Evolution*, 98 PROC. NAT'L ACAD. SCI. 5471, 5474 (2001). As an example, research has found almost no genetic variation between the two separate North American populations of the Monarch butterfly, which have long been kept apart by the Rocky Mountains. ERIC S. GRACE, THE WORLD OF THE MONARCH BUTTERFLY 61-64 (1997); AVISE, *supra* note 85, at 109-11.

[102] *See generally* FRIEDRICH G. BARTH, INSECTS AND FLOWERS: THE BIOLOGY OF A PARTNERSHIP (1985).

[103] *See, e.g.*, WAKEFORD, *supra* note 77, at 108-10; ZIMMER, *supra* note 62, at 175-76.

[104] *See generally* SURINDAR PARACER & VERNON AHMADJIAN, SYMBIOSIS: AN INTRODUCTION TO BIOLOGICAL ASSOCIATIONS (2d ed. 2000) (examining in detail bacterial, viral, fungal, animal, and plant symbiotic relationships, as well as coevolution).

[105] Researchers in the International Human Genome Sequencing Consortium have identified 223 proteins that are very similar to proteins from bacteria. As these genes don't seem to have counterparts in the fruit fly, the worm or weed, these scientists believe that they entered our genomes by horizontal transfer; basically genes from invading bacteria were directly incorporated into our genome. Steven L. Salzberg et al., *Microbial Genes in the Human Genome:*

All of these research results suggest that the idea that there is an ideal "fittest" genome for each species is a myth.[106] Rather, each organism is the product of its own unique genetic and environmental history, through which the number of variants produced are being roughly regulated by intrinsic genetic constraints while the variants that are not adequate for long-term survival are being winnowed out by extrinsic environmental factors.[107]

Nonetheless, despite the absence of an objective, absolute "fittest," many biologists argue that human manipulation of the environment has created so many instances of local extinction and recolonization of populations of a species that, under most conditions, the loss of genetic variability does indeed aggravate the decline of individual populations.[108] They argue that genetic redundancy needs to be retained in order to accommodate future environmental change, and that this makes it important to watch out for narrowing genetic characteristics long before they begin to cause noticeable inbreeding weakness: "[r]apid, extreme environmental change, such as anthropogenic global warming, will place a premium on genetic variability and adaptability of many populations in fragmented environments during the coming centuries."[109]

This kind of concern has led the National Research Council to recommend that "[p]opulations of a species that vary

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*Lateral Transfer or Gene Loss?*, 292 SCI. 1903 (2001).

[106] The Nobel prize-winning economist Herbert Simon had this insight two decades ago: "In a relative sense, the *fitter* survive, but there is no reason to suppose that they are the *fittest* in any absolute sense, or even that we can define what we mean by maximum fitness." HERBERT A. SIMON, REASON IN HUMAN AFFAIRS 69 (1983).

[107] McCauley, *supra* note 62, at 183; POTTS, *supra* note 70, at 206. *See also* BROOKS & WILEY, *supra* note 64, at 103 (explaining that evolution is not the survival of the fittest; it is the "survival of the adequate").

[108] McCauley, *supra* note 62, at 193-94. *See also* JAMES H. BROWN, MACROECOLOGY 159 (1995) (recognizing that feedback mechanisms, such as loss of genetic variability, may hasten extinction); James Mallet, *The Genetics of Biological Diversity: from Varieties to Species*, *in* BIODIVERSITY: A BIOLOGY OF NUMBERS AND DIFFERENCES 13, 27-32 (Kevin J. Gaston ed., 1996) (noting that some formerly rare species retain low genetic diversity even though their populations have expanded); sources cited *supra* and text accompanying notes 68-71. *But see* Ilkka Hanski, *Metapopulation dynamics*, 396 NATURE 41, 44 (1998) ("Convincing empirical evidence is lacking on whether there is reduced genetic variability in species with a classic metapopulation structure.").

[109] Lande, *supra* note 100, at 15.

geographically in degree of genetic distinctiveness would have greater value than populations of a species that are genetically more uniform."[110] Similar concerns underlie biologists' predictions that genetic risks will become dominant issues because of the growing number of small populations in relatively isolated environments.[111] These concerns also underly recommendations that corridors connecting patches of habitat are an important way to improve the genetic variability of isolated species.[112] Some biologists think that resource managers may need to regularly translocate rare species to improve their genetic variability.[113]

State and federal wildlife agencies have paid a good deal of attention to the problem of genetic variation in regard to large, rare species, such as the Florida panther[114] and the black-footed ferret.[115] Agencies have struggled to find ways to give preference

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[110] NAT'L RESEARCH COUNCIL, *supra* note 19, at 32. *See also* NAT'L RESEARCH COUNCIL, SCIENCE AND THE ENDANGERED SPECIES ACT 144-45 (1995) (discussing techniques of assessing extinction risk and limits of scientific knowledge). As Herbert Simon pointed out two decades ago, the variability of both the earth's environment and the number of possible genetic combinations is so great that the history of the world will never allow time to generate more than a fraction of the genetic possibilities. SIMON, *supra* note 106, at 67-68.

[111] Woodruff, *supra* note 101, at 5473. "For example, a timber extraction program designed to conserve biodiversity, in the sense of site species richness, may well reduce biodiversity measured as genetic variation within the tree species harvested." Swingland, *supra* note 13, at 380.

[112] REED F. NOSS & ALLEN Y. COOPERRIDER, SAVING NATURE'S LEGACY: PROTECTING AND RESTORING BIODIVERSITY 61-62, 150-56 (1994).

[113] *See* Woodruff, *supra* note 101, at 5473 ("Nature can no longer be left alone to function, because our actions have doomed countless isolated populations to slow genetic decline and extirpation."). *See also* Richard P. Reading et al., *Towards an Endangered Species Reintroduction Paradigm*, 19 ENDANGERED SPECIES UPDATE 142, 143 (2002) ("[C]onservationists must proceed in the face of uncertainty using the best available data."). The California condor is perhaps the most controversial subject of translocation, with results still not definitively determined. David Kelly, *Welfare State for Vultures*, L.A. TIMES, July 24, 2002, at A1. *See also* U.S. FISH AND WILDLIFE SERVICE, CALIFORNIA CONDOR, *at* http://pacific.fws.gov/condor/default.htm (last visited March 8, 2004). The legal implications of translocation are summarized in DALE D. GOBLE & ERIC T. FREYFOGLE, WILDLIFE LAW: CASES AND MATERIALS 1275-87 (2002).

[114] *See* DIV. OF ENDANGERED SPECIES, U.S. FISH AND WILDLIFE SERVICE, FLORIDA PANTHER, FELIS CONCOLOR CORYI, *at* http://endangered.fws.gov/i/a/saa05.html (last visited March 8, 2004). *See also* Land & Lacy, *supra* note 58, at 100 (discussing inbreeding of Florida panther).

[115] The FWS leads the Black-footed Ferret Recovery Implementation Team, whose stated goal is to "integrate the expertise and resources of various parties contributing to the recovery of the black-footed ferret." BLACK-FOOTED FERRET

to naturally-reared salmon over those reared in hatcheries because the hatchery fish are much less variable genetically.[116] If the prevailing scientific view seems to be that genetic variation becomes a problem only after a species has become rare for other reasons, it is probably unrealistic to expect the agencies to do much more. But this is an area that may well be illuminated soon by new ideas because of the large amount of research now underway.

This discussion has only skimmed the surface of a complex and rapidly changing field of fascinating research. No scientist is suggesting that genetic variability is never relevant to biodiversity, but there has been no consensus in regard to the types of species to which it is relevant or degree of variability that should be treated as the norm.[117]

**PUZZLE #1:**
**TO WHAT EXTENT DOES A LACK OF GENETIC VARIABILITY ITSELF THREATEN THE EXISTENCE OF A SPECIES OR POPULATION? HOW MUCH SHOULD GENETIC VARIABILITY BE PROTECTED?**

### 2. *PHENOTYPIC VARIETY*

Long before genetics was known, observers of the natural world were struck by the extent to which individual organisms of the same species varied in their appearance and behavior.[118] Early evolutionary biologists assumed that fitness preference would cause a single phenotype to evolve for each species.[119] Today,

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RECOVERY IMPLEMENTATION TEAM, WHO ARE WE?, *at http://www.blackfootedferret.org/who.html* (last visited March 8, 2004).

[116] *See* Doremus, *Endangered Species*, *supra* note 9, at 1106-11; Mary H. Ruckleshaus et al., *The Pacific Salmon Wars: What Science Brings to the Challenge of Recovering Species*, 33 ANN. REV. ECOLOGICAL SYS. 665, 682-83 (2002). *See also* discussion at notes 242-255 *infra*.

[117] NAT'L RESEARCH COUNCIL, *supra* note 55, at 23.

[118] *See, e.g.*, GILBERT WHITE, THE NATURAL HISTORY OF SELBORNE, 186-87 (1789). *See also* JOHN I. SPICER AND KEVIN J. GASTON, PHYSIOLOGICAL DIVERSITY AND ITS ECOLOGICAL APPLICATIONS 2 (1999) (discussing antecedents to the authors' discipline).

[119] R. J. Berry, *Phenotype, A Historical Perspective On*, *in* 4 ENCYCLOPEDIA OF BIODIVERSITY 537, 544 (Simon A. Levin ed., 2001). "The idea that evolution produces optimal phenotypes follows from a definition of natural selection which [unrealistically] considers evolution proceeding in a uniform environment." O. T. Solbrig, *Plant Traits and Adaptive Strategies: Their Role in Ecosystem Function*,

many biologists believe that variability of "phenotype"–i.e., appearance and behavior[120]–provides evolutionary advantages,[121] and that it often exists independently of genetic variability.[122]

Phenotypic variability is sometimes correlated with a high degree of genetic variation,[123] but not all genetic variation causes phenotypic variability,[124] and some striking cases of phenotypic variability have developed among groups of organisms that seem to lack substantial genetic variation.[125] Most experts in the field caution that there are yet "no nuclear rules to link phenotype with genotype or phenotypic variety with genetic variety."[126] Thus phenotypic variability and genetic variability should be treated as separate topics.[127]

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*in* BIODIVERSITY AND ECOSYSTEM FUNCTION 97, 106-07 (Ernst-Detlef Schulze & Harold A. Mooney eds., 1994).

[120] "A phenotype commonly refers to the physical appearance of an organism (e.g., a large brown mice [sic] with a short tail), but it can also describe nonvisual properties of an organism, such as physiology or behavior." Berry, *supra* note 106, at 537.

[121] *See* discussion at notes 129-148 *infra.*

[122] *See* discussion at notes 149-155 *infra.*

[123] For example, populations of the common mussel on the Atlantic coast show both genetic and phenotypic variations even though separated only by short distances. NAT'L RESEARCH COUNCIL, *supra* note 19, at 22. *See also* Michael S. Taylor & Michael E. Hellberg, *Genetic Evidence for Local Retention of Pelagic Larvae in a Caribbean Reef Fish*, 299 SCI. 107, 108 (2003) (describing similar findings for a reef-dwelling goby).

[124] *See* Nevo, *supra* note 53, at 195.

[125] Mallet, *supra* note 108, at 16 (stating that though genetically programmed, much phenotypic variation depends on seasonal or maturity changes that affect many individuals in a population regardless of genotype); Ruckleshaus et al., *supra* note 116, at 673 (observing that salmon introduced to new environments show rapid life history divergence but remain almost indistinguishable genetically). *See generally* JOHN C. AVISE, PHYLOGEOGRAPHY: THE HISTORY AND FORMATION OF SPECIES 199-202 (2000) (discussing phylogeographic differentiation in insects).

[126] Berry, *supra* note 119, at 546. *See also* Carlos A. Machado and Marcos A. Antezana, *Diversity, Molecular Level*, *in* 2 ENCYCLOPEDIA OF BIODIVERSITY 179, 181 (Simon A. Levin ed., 2001) (suggesting we still know very little about the relationship between genetic and phenotypic differences among organisms); MASSIMO PIGLIUCCI, PHENOTYPIC PLASTICITY: BETWEEN NATURE AND NURTURE 108 (2001) (explaining that simple theoretical models of the relationship between plasticity and the maintenance of genetic variation have not yielded robust results).

[127] *See* ROBERT POULIN, EVOLUTIONARY ECOLOGY OF PARASITES: FROM INDIVIDUALS TO COMMUNITIES 47 (1998) ("Phenotypic plasticity allows immediate responses to environmental changes and does not result in changes in genotypic frequencies in the population.").

The ability of a particular species to produce phenotypic variability is often described as a function of its "plasticity."[128] Biologists distinguish between at least two common types of phenotypic plasticity, which are sometimes referred to as "noisy" plasticity and "adaptive plasticity."

a. *Noisy plasticity*

This type of phenotypic plasticity occurs where a species responds to unpredictable variability within its environment by producing variable offspring.[129] Humans are, of course, an example of a species that produces offspring of considerable variability. Evolutionary biologists have long believed that sexual reproduction was an evolutionary adaptation that succeeded because it promoted noisy plasticity, and that this type of plasticity "presumably provides the species with at least some individuals that can survive any change that is likely to take place."[130]

As one researcher characterizes it, noisy plasticity can be advantageous because:

> [in] unpredictable microenvironments, the generation of variable progeny, either by genetic means or through heightened sensitivity to small environmental fluctuations occurring during development, can provide a selective advantage by ensuring that *some* progeny are suited to *whatever* the current environment might be.[131]

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[128] Mary Jane West-Eberhard, *Phenotypic Plasticity and the Origins of Diversity*, 20 ANN. REV. ECOLOGY SYSTEMATICS 249 (1989) ("Phenotypic plasticity is the ability of a single genotype to produce more than one alternative form of morphology, physiological state, and/or behavior in response to environmental conditions."). *See also* Beate Nürnberger, *Ecological Genetics*, *in* 2 ENCYCLOPEDIA OF BIODIVERSITY 245, 248 (Simon A. Levin ed., 2001) (discussing surprising amount of phenotypic variation lacking genetic basis).

[129] Sara Via, *The Evolution of Phenotypic Plasticity: What Do We Really Know?*, *in* ECOLOGICAL GENETICS 35, 37 (Leslie A. Real ed., 1994).

[130] GEORGE C. WILLIAMS, ADAPTATION AND NATURAL SELECTION: A CRITIQUE OF SOME CURRENT EVOLUTIONARY THOUGHT 127 (1966). *See also* WALLACE, *supra* note 50, at 113-16 (stating that phenotypic variation enhances the fitness of a population). However, a recent survey of research suggests that phenotypic variation may not have as strong a feedback effect on sexual selection as morphological variation. J. G. Kingsolver et al., *The Strength of Phenotypic Selection in Natural Populations*, 157 AM. NATURALIST 245 (2001).

[131] Via, *supra* note 129, at 37 (emphasis added) ( "When environmentally induced, such 'noisy plasticity' is different from an adaptive reaction norm, because the result is variability in the phenotype within the current environment rather than the production of a particular phenotype.").

Noisy plasticity in animal species is often associated with high rates of reproduction, which allow for, but do not require, greater plasticity.[132]

b. *Adaptive plasticity*

The adaptive type of plasticity occurs when a species assumes different forms in different surroundings.[133] In some cases, the plasticity represents an adaptation to the physical environment.[134] For example, a dandelion that is grown at lower elevations grows into a large plant with big leaves and an erect growing habit, while a clone of the same plant grown at an alpine elevation becomes a small, compact plant growing close to the ground.[135] When strawberry plants grow on the forest floor they assume a phenotype best suited to capture the limited amount of light that penetrates the trees, but if a gap in the canopy opens the plant is capable of changing its form into a "high-light strawberry."[136] Another classic case is the amphibious plant known as the arrowleaf, which has leaves like arrowheads on land, like lily pads in shallow water, and like ribbons in deeper water.[137]

Plasticity also may be an adaptation to the presence of predators.[138] Frogs vary their phenotype according to the number

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[132] Leonard A. Freed, *Extinction and Endangerment of Hawaiian Honeycreepers: A Comparative Approach*, *in* GENETICS AND THE EXTINCTION OF SPECIES 137, 155-57 (Laura F. Landweber and Andrew P. Dobson eds., 1999) (species with low reproduction rates may be more susceptible to extinction due to environmental change than those with high reproductive rates because higher rates tend to generate more plasticity).

[133] EDWARD O. WILSON, CONSILIENCE: THE UNITY OF KNOWLEDGE 137-39 (1998); PIGLIUCCI, *supra* note 126, at 160-72.

[134] Ragan M. Callaway et al., *Phenotypic Plasticity and Interactions Among Plants*, 84 ECOLOGY 1115, 1116-18 (2003).

[135] MERRELL, *supra* note 53, at 42. A particular nematode that is a parasite of freshwater fish varies in mass up to a factor of ninety depending on its environment. POULIN, *supra* note 127, at 48.

[136] LEVIN, *supra* note 39, at 176. Many hybrid crop plants have been bred to encourage the capability of adjusting their phenotype to differing environmental conditions. GROOMBRIDGE & JENKINS, *supra* note 41, at 40-41.

[137] WILSON, *supra* note 133, at 137. *See also* Callaway et al., *supra* note 134, at 1115 (explaining that, as a rule, plants are highly plastic, because plasticity is favored when the environment is variable, when environmental cues are reliable, and where there are costs associated with specialized phenotypes that turn out to be inappropriate).

[138] Callaway et al., *supra* note 121 at 1121-22. *See also* THE ECOLOGY AND EVOLUTION OF INDUCIBLE DEFENSES 286-306 (Ralph Tollrian & C. Drew Harvell

and type of predators in a pond,[139] and daphnia develop particular kinds of spines or armor when they sense chemical cues identifying specific predators.[140] A classic example much discussed in the literature involves moths that evolve through different colors to provide camouflage on trees that change color in response to variable levels of particulate matter in the local air.[141]

The degree of competition may also be a factor in determining levels of plasticity.[142] The same frogs that react to high levels of predation by producing smaller tadpoles will react to high densities of competition from other frogs by producing larger tadpoles.[143] Many phenotypic changes may be the result of complex interactions among many species involving both predation and competition.[144]

In general, much of the adaptive phenotypic plasticity appears to be the result of interactions among species that cause local

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eds., 1999) (discussing evolution of plastic predator-induced defenses).

139 Rick A. Relyea, *Competitor-Induced Plasticity in Tadpoles: Consequences, Cues, and Connections to Predator-Induced Plasticity*, 72 ECOLOGICAL MONOGRAPHS 523, 523 (2002). *See also* Rick A. Relyea, *Fine-tuned Phenotypes: Tadpole Plasticity Under 16 Combinations of Predators and Competitors*, 85 ECOLOGY 172 (2004) (tadpole plasticity responds differently to various combinations of competition and predation).

140 Nürnberger, *supra* note 128, at 248.

141 During the time when England's air was full of soot, biologists noted that a particular moth had changed color to match the darker bark of the trees; as the air became cleaner during the 20th century, the moths gradually returned to a lighter color. L. M. Cook et al., *Postindustrial Melanism in the Peppered Moth*, 231 SCI. 611 (1986). One recent author has criticized the research on which this conclusion was originally based. *See generally* JUDITH HOOPER, OF MOTHS AND MEN: AN EVOLUTIONARY TALE (2002). Nevertheless, the phenomenon is readily observed and continues to evolve as air quality improves. Bruce S. Grant, *Sour Grapes of Wrath*, 297 SCI. 940 (2002) (reviewing and criticizing Hooper's book).

142 *See* Callaway et al., *supra* note 134, at 1119-21.

143 Relyea, *supra* note 139, at 523 ("[T]hese animals have an amazing ability to sense changes in their environments and respond in very precise ways."). The global decline in frogs may benefit some of the tadpoles' competitors, such as mosquito larvae, with adverse impacts on human health. *See* A. Mokany & R. Shine, *Competition Between Tadpoles and Mosquito Larvae*, 135 OECOLOGIA 615, 619 (2003). *See also* Oswald J. Schmitz et al., *Linking Individual-Scale Trait Plasticity to Community Dynamics,* 84 ECOLOGY 1081, 1081-82 (2003) (introducing a series of papers on the impact of phenotypic plasticity upon the relations among various species in a community).

144 Earl E. Werner & Scott D. Peacor, *A Review of Trait-Mediated Indirect Interactions in Ecological Communities,* 84 ECOLOGY 1083, 1085, 1093-94 (2003); Lars-Anders Hansson, *Plasticity in Pigmentation Induced by Conflicting Threats from Predation and UV Radiation*, 85 ECOLOGY 1005 (2004).

populations of a particular species to evolve particular forms or behavior patterns as a way of adapting to other species with which they interact.[145] Adaptive plasticity may cause separate populations of a species to evolve into noticeably different phenotypes occupying different geographic areas.[146] When this happens, taxonomists often classify each population as a separate subspecies, race, or variety on the basis of its morphology (appearance and behavior).[147] There is little agreement among biologists on universal criteria for deciding whether different populations of a species constitute separate subspecies.[148]

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[145] The literature is reviewed in Anurag A. Agrawal, *Phenotypic Plasticity in the Interactions and Evolution of Species*, 294 SCI. 321, 321-25 (2001). Ecologists study this kind of phenotypic variation among different local populations as "natural experiments" because "each population is the result of a continual selection process" that adapts the organism to the local conditions, so a study of the variations helps explain the ecology of the species. Sanderson & Harris, *supra* note 69, at 44. There is still a good deal of disagreement among ecological geneticists about the nature of the evolutionary processes that produce phenotypic plasticity. Sara Via et al., *Adaptive Phenotypic Plasticity: Consensus and Controversy*, 10 TRENDS IN ECOLOGY & EVOLUTION 212, 212 (1995); S. E. Sultan, *Phenotypic Plasticity for Fitness Components in* Polygonum *Species of Contrasting Ecological Breadth*, 82 ECOLOGY 328, 328-29 (2001) (stating that more research is needed to fully evaluate general relationship of phenotypic plasticity to fitness); ALESSANDRO MINELLI, BIOLOGICAL SYSTEMATICS: THE STATE OF THE ART 57-58 (1993) (asserting that molecular systematics needs to take better account of intraspecific variability).

[146] *See* Agrawal, *supra* note 145, at 321.

[147] See, for example, the varied appearance of the Northern and Caribbean races of the short-eared owl pictured in DAVID ALLEN SIBLEY, THE SIBLEY GUIDE TO BIRDS 273 (2000). For a critique of this practice, see H. Douglas Pratt & Thane K. Pratt, *The Interplay of Species Concepts, Taxonomy, and Conservation: Lessons from the Hawaiian Avifauna*, 22 STUD. AVIAN BIOLOGY 68, 77-78 (2001).

[148] JODY HEY, GENES, CATEGORIES, AND SPECIES: THE EVOLUTIONARY AND COGNITIVE CAUSES OF THE SPECIES PROBLEM 163 (2001) ("There exist no theories on the nature or origin of subspecies."); JUDITH E. WINSTON, DESCRIBING SPECIES: PRACTICAL TAXONOMIC PROCEDURE FOR BIOLOGISTS 324-30 (1999) (describing varying rules for naming subspecies of different organisms). *See also* Jacqueline Lesley Brown, *Preserving Species: The Endangered Species Act Versus Ecosystem Management Regime, Ecological and Political Considerations, and Recommendations for Reform*, 12 J. ENVTL. L. & LITIG. 151, 190-92 (1997). One result is that the listing of subspecies as endangered has often been highly controversial. Doremus, *Endangered Species*, *supra* note 9, at 1104. *But see* Michael W. Bruford, *Biodiversity: Evolution, Species, Genes*, *in* CONSERVING BIRD BIODIVERSITY: GENERAL PRINCIPLES AND THEIR APPLICATION 1, 18 (Ken Norris & Deborah J. Pain eds., 2002) ("Although seen as a somewhat esoteric exercise by those scientists concerned with protecting as much biodiversity as rapidly as possible, incorporating variation

c. *Plasticity without genetic diversity*

Early geneticists assumed that most phenotypic variability was genetically based, but studies are increasingly finding a high degree of phenotypic variability among genetically identical groups of organisms; a recent review found that "a surprising amount of intraspecific phenotypic variation lacks a genetic basis."[149] For example, coral reef fish of a particular species cannot be genetically differentiated based on location, but they have evolved significantly different behavior patterns for different types of local environments.[150] Corals themselves exhibit phenotypic plasticity based on the degree of wave energy and light level.[151]

Does the evolutionary process normally prefer phenotypic variability (plasticity)? Smithsonian anthropologist Rick Potts argues that it does, and he calls the process by which evolution promotes plasticity "variability selection"; i.e., plasticity is a trait that natural selection encourages because it promotes fitness to variable environments.[152] He argues that any particular species may have survived for millions of years, during which time it faced wide differences in survival conditions.[153] Evolution would

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below the species into management programmes could in fact hold the key to effective conservation in the future."). GOBLE & FREYFOGLE, *supra* note 113, at 1183 ("Were there a truth-in-titling requirement for federal statutes, the Endangered Species Act would be titled the Endangered Subspecies and Vertebrate-Distinct-Populations Act."). Of course some molecular biologists would like to see the entire concept of species reevaluated, as discussed at notes 327-333 *infra*. Harvard Biologist Edward O. Wilson believes that the growing use of phylogenetics will cause many subspecies to be re-labeled species. Edward O. Wilson, *The Creation of Biodiversity*, *in* NATURE AND HUMAN SOCIETY: THE QUEST FOR A SUSTAINABLE WORLD 22, 24 (Peter H. Raven ed., 2000). *See also* Pratt & Pratt, *supra* note 147, at 78-80.

[149] Nürnberger, *supra* note 128, at 248. *See also* PIGLIUCCI, *supra* note 126, at 113-16 (discussing "plasticity genes" which control the phenotype by responding to specific environmental stimuli, triggering specific morphological changes); RICHARD LEWONTIN, THE TRIPLE HELIX: GENE, ORGANISM AND ENVIRONMENT 120 (2000).

[150] Robert R. Warner, *The Use of Phenotypic Plasticity in Coral Reef Fishes as Tests of Theory in Evolutionary Ecology*, *in* THE ECOLOGY OF FISHES ON CORAL REEFS 387 (Peter F. Sale ed., 1991).

[151] Knowlton & Weigt, *supra* note 88, at 201-02. Of course, all of these phenotypic changes are presumably the result of natural selection rather than any conscious intent of the species, at least as far as we know. *But c.f.* Thaler, *supra* note 66, at 224.

[152] POTTS, *supra* note 70, at 231.

[153] *Id*.

have favored retention of those mutations that might help the species adapt to future environmental change.[154] Potts argues that the human species, in particular, has developed a high degree of phenotypic plasticity, and that this plasticity has probably contributed to our ability to adapt to so many different environments.[155]

If plasticity is truly a way in which organisms enhance their ability to survive,[156] then the logical next question is whether plasticity *itself* is a form of biodiversity that is equally as important as the more widely-understood diversity among species?[157] From a legal standpoint, this is apparently a new question. Little attention has been paid to the issue of whether species that exhibit great phenotypic variety should receive more protection than those that don't.[158] Some biologists have expressed concern that selective harvesting of certain species may be decreasing their plasticity; for example, legal rules that promote the harvesting of only the largest fish may have the effect of encouraging the species to evolve into a smaller body type.[159]

Study of phenotypic plasticity can contribute to the important need to understand resilience at larger ecological scales.[160] NMFS,

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[154] *Id*. at 232.

[155] *See id*. at 243-247.

[156] Rick A. Relyea, *Costs of Phenotypic Plasticity*, 159 AM. NATURALIST 272, 280 (2002) (documenting fitness benefits of plasticity); Trevor D. Price et al., *The Role of Phenotypic Plasticity in Driving Genetic Evolution*, 270 PROC. ROYAL SOC'Y LONDON 1433, 1438 (2003) (exploring question of whether benefits of plasticity might be reduced by unidirectional environmental change).

[157] Carol J. Bult et al., *The Impact of Rapid Gene Discovery Technology on Studies of Evolution and Biodiversity*, *in* BIODIVERSITY II: UNDERSTANDING AND PROTECTING OUR BIOLOGICAL RESOURCES 289, 295-96 (Marjorie L. Reaka-Kudla et al. eds., 1997) ("biodiversity incorporates genetic and ecological variation, through space and time, of individuals within populations as well as monophyletic groups of organisms . . . ."). *See also* Kunihiko Kaneko & Tetsuya Yomo, *Symbiotic Sympatric Speciation through Interaction-Driven Phenotype Differentiation*, 4 EVOLUTIONARY ECOLOGY RES. 317, 344 (2002) (suggesting that formation of a few distinct phenotypes is often the first step in speciation).

[158] *See*, *e.g.*, Doremus, *Endangered Species*, *supra* note 9, at 1105-22 (arguing that focusing on genetic resources alone doesn't necessarily promote ESA's goals, and noting theoretical and practical shortcomings of the notion of a species' "viability" in interpreting the ESA).

[159] Lande, *supra* note 87, at 10; Ebsen M. Olsen et al., *Maturation Trends Indicative of Rapid Evolution Preceded the Collapse of Northern Cod*, 428 NATURE 932 (2004).

[160] As one researcher puts it:

The long-term health of ecological systems will depend upon the ability of which administers the ESA in regard to marine species, is well aware of the potential problems of intentional and unintentional manipulation of the phenotypic characteristic of these species as a result of a wide range of factors such as fisheries regulation, fishing technology, tropical fish collection, aquaculture, and fish hatcheries.[161] The world has in effect been conducting a grand experiment to determine the extent to which any or all of these factors will result in marine species that are larger or smaller, healthier or sicker, more or less safe to eat, and so on.[162] While one can certainly criticize the nature and extent of these management efforts, they should at least furnish a body of data from which it may be easier to ascertain the desirability of emphasizing the importance of phenotypic variability.

## PUZZLE #2:
## SHOULD WE PROTECT PHENOTYPIC DIVERSITY, OR PLASTICITY OF SPECIES, WHICH ENABLES SPECIES TO ADAPT TO FUTURE ENVIRONMENTAL CHANGE?

### 3. *Are all species equal?*

Given the extent to which science and technology have changed since 1735, it is quite remarkable that our idea of "species," the central classification in most analyses of biodiversity, is basically the same as it was in the first edition of a book published in that year by a Swedish botany professor, Karl

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organisms to adapt and respond to changes in their biotic and abiotic environment. The methods for studying adaptive evolution in contemporary populations provided by current ecological genetics will prove equally important in assessing the ability of organisms to respond to both local and global aspects of environmental change, including response to anthropogenic stresses in disturbed ecosystems.

Real, *supra* note 95, at xiv. *See also* BRIAN A. MAURER, UNTANGLING ECOLOGICAL COMPLEXITY: THE MACROSCOPIC PERSPECTIVE 164 (1999).

161 *See* Rosamond L. Naylor et al., *Aquaculture: A Gateway for Exotic Species*, 294 SCI. 1655 (2001) (noting agencies opposition to introduction of non-native species). Although diversity of major lineages (phyla and classes) is much greater in marine environments than on land, species diversity seems to be much lower in the oceans, presumably because marine waters are less variable in space and time than the terrestrial environment. GROOMBRIDGE & JENKINS, *supra* note 41, at 117.

162 *See* NAT'L RESEARCH COUNCIL, SUSTAINING MARINE FISHERIES 1-2 (1999).

Von Linné, known as Linnaeus.[163] The widespread adoption of his system of classification reflected its ease of use,[164] which met the need of eighteenth-century European naturalists to impose some sort of order on the myriads of new plants and animals that were arriving from around the world, creating the fear "that the world was so complex that its true order would forever remain unknowable."[165]

The current version of the Linnaean system of classification works in the following way: committees of scientists who specialize in certain types of organisms decide which organisms should be categorized as members of a particular species.[166] They will also decide where the species fits into a hierarchy consisting of genus, family, order, class, and so forth.[167] The findings of the committees are regularly updated and published, and they have been accepted throughout the world as the decisive opinion on where an organism fits into the Linnaean system.[168]

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[163] KARL VON LINNÉ, SYSTEMA NATURAE (1st ed. 1735). *See* Walter J. Bock, *Biological Classification*, *in* 2 SYNOPSIS AND CLASSIFICATION OF LIVING ORGANISMS 1067 (Sybil P. Parker ed. 1982).

[164] LISBET KOERNER, LINNAEUS: NATURE AND NATION 39-40 (1999).

[165] PETER J. BOWLER, THE NORTON HISTORY OF THE ENVIRONMENTAL SCIENCES 159 (Am. ed., 1993).

[166] Bisby et al., *supra* note 94, at 31; WINSTON, *supra* note 148, at 20-21, 30-31. *See also* Richard L. Mayden, *A Hierarchy of Species Concepts*, *in* SPECIES: THE UNITS OF BIODIVERSITY 381, 389 (Michael F. Claridge et al. eds., 1997) (noting that scientists develop species concepts to suit individual researchers' needs). Two organizations that oversee the process are, for animals, the London-based International Commission on Zoological Nomenclature and, for plants, the International Bureau for Plant Taxonomy and Nomenclature based in Utrecht. John O. Corliss, *The History and Role of Nomenclature in the Taxonomy and Classification of Organisms*, *in* 2 SYNOPSIS AND CLASSIFICATION OF LIVING ORGANISMS 1065, 1065-66 (Sybil P. Parker ed., 1982); WINSTON, *supra* note 148, at 28-30.

[167] Corliss, *supra* note 166, at 1065.

[168] *See id*.; Bisby et al., *supra* note 94, at 31; WINSTON, *supra* note 148, at 13-35. The study of the kinds and diversity of organisms and of any and all relationships among them is known as "systematics." Within systematics, the theory and practice of classifying organisms is known as "taxonomy." Bisby et al., *supra* note 94, at 28. *See also* Joel L. Cracraft, *Charting the Biosphere: Building Global Capacity for Systematics Science*, *in* NATURE AND HUMAN SOCIETY: THE QUEST FOR A SUSTAINABLE WORLD 374, 376-77 (Peter H. Raven ed., 1999); Michael J. Novacek, *The Meaning of Systematics and the Biodiversity Crisis*, *in* SYSTEMATICS, ECOLOGY AND THE BIODIVERSITY CRISIS 101, 103 (Niles Eldredge ed., 1992). For further discussion of systematics, see *infra* notes 255-331.

In discussions of biodiversity in the general media, the category of species has played a predominant role.[169] "Species richness" is the term used by biologists to describe the number of different species present in a particular area, and in common usage some people seem to equate species richness and biodiversity.[170] In addition to local species richness, biologists consider species richness at the global level, recognizing that in some instances local species richness could work to the disadvantage of global biodiversity if, for example, an endemic species was threatened with extinction by numerous competitors.[171]

Today, the survival of the entire Linnaean system of classification is the topic of scientific debate.[172] But before taking up issues that go to the very existence of the Linnaean classification system, it is important to consider issues that arise in the interpretation of biodiversity *within* the existing system. Today, many scientists balk at using simple arithmetic to count species, and are searching for methods of categorization that would give greater or lesser importance to certain categories of species.[173] Some of the categories that have been identified are focal species, unique species, sibling species, and endemic species. Each of these will be discussed in turn.

a. *Focal species*

One of the more intense debates among ecologists is over the issue of whether certain "focal species" are essential components of biodiversity and, if so, how they are to be identified. Ecologists recognize that there are often particular species (or networks of interacting species) that "have key, broad-scale ecosystem-level effects."[174] Some biologists have argued that we should concentrate protection on these species, rather than on either the

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[169] Adams et al., *supra* note 20, at 634.

[170] Kevin J. Gaston, *Species Richness: Measure and Measurement*, *in* BIODIVERSITY: A BIOLOGY OF NUMBERS AND DIFFERENCE 77 (Kevin J. Gaston ed., 1996).

[171] NAT'L RESEARCH COUNCIL, *supra* note 19, at 26-28.

[172] *See infra* notes 327-353.

[173] *See* NAT'L RESEARCH COUNCIL, *supra* note 19, at 23-24 (noting that simple species counts are often inadequate). For suggestions for prioritizing species under the ESA, see Doremus, *Biological Diversity*, *supra* note 9, at 328-33.

[174] V. H. Dale et al., *Ecological Principles and Guidelines for Managing the Use of Land*, 10 ECOLOGICAL APPLICATIONS 639, 650 (2000).

rarest or the most intensively studied species, as we do today.[175] The term "focal species" is used to encompass a number of categories of species hereinafter discussed, including "umbrella," "indicator" and "keystone" species.[176]

i. *Umbrella species*

Large animals tend to attract public attention, which in turn increases conservation funding options.[177] But do larger animals at the top of the food web play an especially significant role in preserving overall biodiversity, and do they therefore deserve greater protection than other species?[178] For example, if the number of large fish in a lake affects phytoplankton composition, which then alters the productivity of the lake, will control of the large fish effectively control the lake's ecological processes?[179] If

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[175] *See, e.g.*, David L. Pearson, *Selecting Indicator Taxa for the Quantitative Assessment of Biodiversity*, *in* BIODIVERSITY: MEASUREMENT AND ESTIMATION 75, 76 (D.L. Hawksworth ed., 1995).

[176] Dale et al., *supra* note 174, at 650. *See also* Carlos Carroll et al., *Carnivores as Focal Species for Conservation Planning in the Rocky Mountain Region*, 11 ECOLOGICAL APPLICATIONS 961, 976 (2001) (discussing how a combination of focal species may be more effective for conservation purposes than any single species presumed to be an umbrella).

[177] It has been argued that large "charismatic" species such as pandas and gorillas deserve special protection because their popular appeal creates public support for biodiversity. Paul Jepson & Susan Canney, *Biodiversity Hotspots: Hot for What?*, 10 GLOBAL ECOLOGY & BIOGEOGRAPHY 225, 226 (2001) (suggesting that criteria for hotspots that rank all species as equal are unrealistic in terms of obtaining public support). Such species are sometimes referred to as "flagship species." Reed Noss, *From Endangered Species to Biodiversity*, *in* BALANCING ON THE BRINK OF EXTINCTION 227, 234-35 (Kathryn A. Kohm ed., 1991). *See also* LOMBORG, *supra* note 25, at 253 ("It is not clear how much political backing the rainforest lobby could have attracted if the biologists had emphasized that what would be lost would primarily be insects, bacteria and viruses."). For a perspective on Lomborg's work, see Douglas A. Kysar & James Salzman, *Environmental Tribalism*, 97 MINN. L. REV. 1099 (2003).

[178] TAKACS, *supra* note 9, at 63-64. *See also* Brian Miller et al., *The Importance of Large Carnivores to Healthy Ecosystems*, 18 ENDANGERED SPECIES UPDATE 202, 203 (2001) (under a top-down system of regulation the impact of carnivores ripples down through the trophic levels of the ecosystem). If an isolated patch of habitat is too small to support large predators, the predators' normal prey may have higher population densities, with potentially significant consequences down the food chain. ROBERT J. WHITTAKER, ISLAND BIOGEOGRAPHY: ECOLOGY, EVOLUTION, AND CONSERVATION 224 (1998).

[179] Dale et al., *supra* note 174, at 650. Some biologists think that changes in the top predator may have greater impact in aquatic systems than in terrestrial systems. Mark A. McPeek, *The Consequences of Changing the Top Predator in a Food Web: A Comparative Experimental Approach*, 68 ECOLOGICAL

so, the large fish would be referred to as "umbrella species" because their protection also protects species in the trophic levels below them.[180]

Some ecologists emphasize that the predators at the top of the food chains tend to exert "top-down effects" on ecological system processes,[181] and that the removal or replacement of any such species produces a measurable response in overall ecological system variables.[182] One interesting example is the impact of the removal of wolves and grizzly bears from the greater Yellowstone area.[183] The study of this occurrence compared riparian areas in

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MONOGRAPHS 1, 18 (1998); Jeremy B. C. Jackson, *What Was Natural in the Coastal Oceans?*, 98 PROC. NAT'L ACAD. SCI. 5411, 5414-16 (2001) (overharvesting of large vertebrates triggered collapse of Caribbean coral reefs). Many biologists believe that the highest rate of biodiversity loss is taking place in freshwater environments. Osvaldo E. Sala et al., *Global Biodiversity Scenarios for the Year 2100*, 287 SCI. 1770, 1772 (2000).

[180] Miller, *supra* note 178, at 202; TAKACS, *supra* note 9, at 63-64 (pointing out that larger species require larger habitat ranges, and therefore preserving megafauna preserves potential habitat for other organisms). In addition, some biologists, such as Michael Soulé, argue that animals at the top trophic levels deserve more protection because they are more extinction-prone. John Terborgh, *Preservation of Natural Diversity: The Problem of Extinction Prone Species*, 24 BIOSCIENCE 715, 719 (1974). For a discussion of the categories of species that have featured prominently in the history of extinction, including (1) species on the top of the food chain and (2) widespread species with poor dispersal and colonization ability, see *id*. at 719-21.

[181] Jackson *supra* note 179, at 5414-16; McPeek *supra* note 179, at 18. *See also* Erica Fleishman et al., *Empirical Validation of a Method for Umbrella Species Selection*, 11 ECOLOGICAL APPLICATIONS 1489, 1494-95 (2001). For an interesting study that found that an umbrella species actually produced overall increases in the populations of many of its prey through indirect effects, see generally Cristina Bondavalli & Robert E. Ulanowicz, *Unexpected Effects of Predators upon Their Prey: The Case of the American Alligator*, 2 ECOSYSTEMS 49 (1999).

[182] Sanderson & Harris, *supra* note 69, at 112. If the organism is mobile and moves among a number of different ecosystems it will exert top-down influences in all of the ecosystems it utilizes. *Id*. A focus on umbrella species such as large predators that play a key role in the behavior of species lower on the food chain is likely to extend the scope of reserve design beyond the bounds of any single ecosystem, given the wide range of territory covered by such predators as eagles or cougars. In general, the larger the area of the reserve the more diverse its population is likely to be. MICHAEL L. ROSENZWEIG, SPECIES DIVERSITY IN SPACE AND TIME 381-83 (1995). In addition the argument has been made that, "non-biologist decision makers are more likely to respond" to taxa that are uniquely represented in their country in disproportionate abundance or, alternatively, in only small remnants. Pearson, *supra* note 160, at 77. *See also* Doremus, *Endangered Species*, *supra* note 9, 1135.

[183] Joel Berger et al., *A Mammalian Predator-Prey Imbalance: Grizzly Bear*

the National Parks, in which hunting was prohibited, with comparable areas outside the parks, in which hunting was allowed.[184] The Park areas had high moose populations, which substantially impacted the willow communities and reduced the populations of birds dependent on those communities.[185] Where hunting served as a proxy for large predators, moose were rare and the bird species richness was higher.[186]

Other ecologists suggest that the loss of all types of large mammals—herbivores as well as carnivores—is having adverse effects on ecological processes in many areas.[187] A relationship between size and biodiversity is underscored by the apparent tendency of evolution to produce gradually increasing body size throughout the animal kingdom.[188] In general, there is less biodiversity at the higher levels of the food web.[189] Large body size repeatedly appears as a characteristic associated with high rates of extinction during episodes of environmental change, presumably because large size constrains population density, and because many large organisms reproduce slowly.[190]

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*and Wolf Extinction Affect Avian Neotropical Migrants*, 11 ECOLOGICAL APPLICATIONS 947 (2001).

[184] *Id*. at 950.

[185] *Id*. at 951.

[186] *Id*. at 953-54.

[187] R. Dirzo, *Plant-Mammal Interactions: Lessons for Our Understanding of Nature, and Implications for Biodiversity Conservation*, *in* ECOLOGY: ACHIEVEMENT AND CHALLENGE 319, 326-34 (Malcolm C. Press et al. eds., 2001); J. Emmett Duffy, *Biodiversity Loss, Trophic Skew and Ecosystem Functioning*, 6 ECOLOGY LETTERS 680 (2003) (loss of large vertebrate consumers has more effect on ecological functions than changes in plant composition).

[188] BROWN, *supra* note 108, at 201 (positing that the trend is toward increases in energy use, complexity, and body size, and stating, "Those individuals within species and those species within biotas that obtain a larger share of the energy are, on average, able to produce more descendants."). For a critique of this theory, see STEPHEN JAY GOULD, FULL HOUSE: THE SPREAD OF EXCELLENCE FROM PLATO TO DARWIN 147-66 (1996).

[189] ROSENZWEIG, *supra* note 182, at 77. For an interesting but somewhat controversial analysis of the relationship between body size and population size, see PAUL COLINVAUX, WHY BIG FIERCE ANIMALS ARE RARE: AN ECOLOGIST'S PERSPECTIVE 18-31 (1978).

[190] BROWN, *supra* note 108, at 162-65. Whether experimental results support this thesis is yet to be determined. *Id.* at 163-65. Biologists aren't sure whether there is a relationship between the number of species within a taxon and body size. Fifty years ago, many biologists thought there were more intermediate size species than either large or small ones, but although this is typical it is not universal. ROSENZWEIG, *supra* note 182, at 73-77. Large organisms with a

Not all ecologists agree that the top predators tend to serve as focal species.[191] University of California at Santa Barbara professor Daniel Botkin says that the "idea that top predators precisely regulate the balance of prey populations in an ecosystem is . . . a myth."[192] He argues that the elimination of predators may cause short term increases in prey populations, but that these peaks are short-lived.[193] In general, however, support for carnivore protection remains strong.[194]

ii. *Keystone species*

Larger species are not the only ones that have an indirect impact on biodiversity; any species that has a greater effect on ecological processes than would be predicted from its size or abundance is referred to as a "keystone species."[195] Keystone species "have been demonstrated or suggested to occur in all of the world's major ecological systems."[196] For example, the Red-cockaded woodpecker is the only species that excavates nest

preference for rare habitat and poor dispersal capabilities are often at the greatest risk for extinction. Mark E. Ritchie, *Populations in a Landscape Context: Sources, Sinks and Metapopulations*, *in* WILDLIFE AND LANDSCAPE ECOLOGY: EFFECTS OF PATTERN AND SCALE 160, 181 (John A. Bissonette ed., 1997). *See also* Leonard V. Polishchuk, *Conservation Priorities for Russian Mammals*, 297 SCI. 1123 (2002) (noting that slow-reproducing, long-lived, and large species often become extinct first, and that the Siberian tiger and polar bear are primary foci of Russian conservation).

[191] For a critique of the "megafauna bias" in discussions of biodiversity, see Norman I. Platnick, *Patterns of Biodiversity*, *in* SYSTEMATICS, ECOLOGY AND THE BIODIVERSITY CRISIS 15, 18-19 (Niles Eldredge ed., 1992). For an interesting study of the potential use of butterflies as umbrella species, see Erica Fleishman et al., *A New Method for Selection of Umbrella Species for Conservation Planning*, 10 ECOLOGICAL APPLICATIONS 569 (2000).

[192] DANIEL B. BOTKIN, NO MAN'S GARDEN: THOREAU AND A NEW VISION FOR CIVILIZATION AND NATURE 165-66 (2001).

[193] *Id*. at 166. *See also* Franck Courchamp et al., *Removing Protected Populations to Save Endangered Species*, 302 SCI. 1532 (2003) (noting that it may be necessary to remove all golden eagles from Santa Cruz Island, CA, in order to save endangered subspecies of island fox).

[194] *See, e.g.*, Jepson & Canney, *supra* note 177, at 225-26; ROSENZWEIG, *supra* note 182, at 381-83.

[195] Mary E. Power et al., *Challenges in the Quest for Keystones*, 46 BIOSCIENCE 609 (1996); Dale et al., *supra* note 174, at 650. Although the word seems to be used with quite broad connotations today, some biologists argue that "keystone" species should be restricted to top predators that prevent monopolization of space at lower trophic levels. Robert D. Davic, *Herbivores as Keystone Predators*, 6 CONSERVATION ECOLOGY 2 (2002).

[196] Power et al., *supra* note 195, at 611.

cavities in living trees in pine forests in the southern United States, and many other species of birds, mammals, reptiles, amphibians, and insects rely on these nest cavities.[197]

A growing body of research in microbiology suggests that the role of microbes in ecological processes is far more important than scientists realized a few decades ago, so that microbial species may be the keystone species of some ecological systems.[198] The legal protection of small species has lagged far behind the protection of large species.[199] A literal interpretation of species richness would suggest that the more species that survive the greater the richness,[200] but in practice the measure of biodiversity has tended to concentrate on the larger organisms and to ignore invertebrates, fungi, and bacteria,[201] which are often divided into many more species than larger organisms.[202]

The traditional concept of species doesn't work well as applied to many microorganisms, because the traditional definition of species depended on the ability to determine whether the organisms were capable of freely interbreeding with each other, which is of no value for the many microorganisms that do not

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[197] Dale et al., *supra* note 174, at 651.

[198] T. Martin Embley et al., *Biodiversity at the Molecular Level: the Domains, Kingdoms and Phyla of Life*, *in* BIODIVERSITY: MEASUREMENT AND ESTIMATION 21 (D.L. Hawksworth ed., 1995) ("[P]ractically all key environmental processes are driven by microbial activity . . . ."); NAT'L RESEARCH COUNCIL, *supra* note 55, at 25; Vandenkoornhuyse et al., *supra* note 82, at 2051 (stating that fungi mediate many ecological processes). *See also* WILSON, *supra* note 57, at 141-48 ("[B]acteria . . . are so important in medicine, ecology, and molecular genetics . . . ."); Donald A. Phillips & Donald R. Strong, *Rhizosphere Control Points: Molecules to Food Webs*, 84 ECOLOGY 815 (2003) (introducing a special feature containing articles on how plants use microbial factors to monitor the external soil environment and regulate plant functions such as root growth).

[199] *See* Jerry F. Franklin, *Preserving Biodiversity: Species, Ecosystems, or Landscapes?*, 3 ECOLOGICAL APPLICATIONS 202 (1993); Lawrence L. Master et al., *Vanishing Assets: Conservation Status of U.S. Species*, *in* PRECIOUS HERITAGE: THE STATUS OF BIODIVERSITY IN THE UNITED STATES 93, 106-10 (Bruce A. Stein et al. eds., 2000). The historical policy preference for protection of vertebrates is discussed in Brown, *supra* note 148, at 187-90.

[200] *See supra* note 41 and accompanying text.

[201] John Copeland Nagle, *Playing Noah*, 82 MINN. L. REV. 1171, 1197-99 (1998). *See also* Franklin, *supra* note 199, at 202.

[202] P. M. Hammond, *Practical Approaches to the Estimation of Biodiversity in Species Groups*, *in* BIODIVERSITY: MEASUREMENT AND ESTIMATION 119, 120 (D.L. Hawksworth ed., 1995) (explaining that species richness patterns of small organisms do not mirror the species richness patterns of larger organisms).

reproduce sexually.[203] Molecular biology is beginning to provide a more useful framework for classifying and interpreting microbial diversity.[204]

Biologists are finding that the role of bacteria and fungi in the soil, for example, may prove to be so essential that we will need to turn the umbrella upside down and think about "infrastructure species" that are essential to the makeup of ecological systems.[205] In marine systems, the role of species toward the bottom of the food web, such as mollusks, may also turn out to be "infrastructure species."[206]

Another category of species that may deserve keystone status are the "ecological system engineers."[207] These are organisms that cause physical change in the ecological system in ways that directly or indirectly control the availability of resources to other organisms.[208] The classic example is the beaver, which by

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[203] *See, e.g.*, Wilson, *supra* note 148, at 22-23.

[204] Norman R. Pace, *Microbial Diversity and the Biosphere*, *in* NATURE AND HUMAN SOCIETY: THE QUEST FOR A SUSTAINABLE WORLD 117, 121-22 (Peter H. Raven ed., 2000). It would unduly lengthen this article to address the issue of how microbiologists separate one species from another. Suffice it to say that the introduction of new DNA identification techniques, and the problems associated with categorizing numerous forms of newly discovered microbes, make these issues increasingly important and contentious. *See generally* Sogin & Hinkle, *supra* note 67. The problem of categorizing different microbes is staggering, but the issue is finally beginning to get the attention it deserves. *See, e.g.*, Embley et al., *supra* note 180, at 21; Dunlap, *supra* note 72, at 191-92.

[205] *See, e.g.*, Diana H. Wall & Ross A. Virginia, *The World Beneath Our Feet: Soil Biodiversity and Ecosystem Functioning*, *in* NATURE AND HUMAN SOCIETY: THE QUEST FOR A SUSTAINABLE WORLD 225, 227-28 (Peter H. Raven ed., 2000).

[206] Thomas E. Lovejoy, *The Quantification of Biodiversity: An Esoteric Quest or a Vital Component of Sustainable Development*, *in* BIODIVERSITY: MEASUREMENT AND ESTIMATION 81, 85 (D.L. Hawksworth ed., 1995).

[207] S.T.A. Pickett et al., *Generation of Heterogeneity in Organisms: Creation, Maintenance and Transformation*, *in* THE ECOLOGICAL CONSEQUENCES OF ENVIRONMENTAL HETEROGENEITY 33, 41-43 (M. J. Hutchings et al. eds., 1999). For a concise review of the various ways that animals impact the terrestrial landscape, see Carol A. Johnston, *Effects of Animals on Landscape Pattern*, *in* MOSAIC LANDSCAPES AND ECOLOGICAL PROCESSES 57-72 (Lennart Hansson et al. eds., 1995).

[208] Clive G. Jones et al., *Positive and Negative Effects of Organisms as Physical Ecosystem Engineers*, 78 ECOLOGY 1946, 1947 (1997). For a controversial suggestion that such "foundation species" should replace the idea of keystone species, see John F. Bruno et al., *Inclusion of Facilitation into Ecological Theory*, 18 TRENDS ECOLOGY & EVOLUTION 119 (2003), discussed in Ben Shouse, *Conflict over Cooperation*, 299 SCI. 644 (2003).

building dams creates major alterations of the environment.[209] Similarly, catfish and other bottom feeders can create major alterations of freshwater systems.[210]

Very large animals, such as elephants, create ecological effects by trampling vegetation; large plants, such as old forest trees, also act as engineers when they cast shade, aerate the soil, and deposit leaves into forest streams.[211] In other instances, very small organisms can be ecosystem engineers, like the microbes that serve as ecosystem engineers by "paving" the Negev desert.[212] Although ecosystem engineering may reduce biodiversity in certain local situations, it is believed to enhance species richness at the landscape level by increasing net habitat diversity.[213] But drawing a clear distinction between the environmental changes caused by humans and those caused by nonhuman engineers is not so easy.[214]

University of Tennessee ecologist Daniel Simberloff has argued that management of keystone species may often be the most efficient way of protecting ecological systems.[215] This

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[209] Johnston, *supra* note 207, at 59-65.

[210] Jeffrey Levinton, *Bioturbators as Ecosystem Engineers: Control of the Sediment Fabric, Inter-Individual Interactions, and Material Fluxes*, *in* LINKING SPECIES AND ECOSYSTEMS 29, 29-30 (Clive G. Jones & John H. Lawton eds., 1994). Virtually all organisms change their environment to some degree. LEWONTIN, *supra* note 149, at 54 (explaining that organisms actively construct a world around themselves).

[211] Steward T. A. Pickett & Kevin H. Rogers, *Patch Dynamics: The Transformation of Landscape Structure and Function*, *in* WILDLIFE AND LANDSCAPE ECOLOGY: EFFECTS OF PATTERN AND SCALE 101, 102-3, 109 (John A. Bissonette ed., 1997).

[212] Joseph Alper, *Ecosystem "Engineers" Shape Habitats for Other Species*, 280 SCI. 1195, 1195-96 (1998). *See also* Jayne Belnap, *The World at Your Feet: Desert Biological Soil Crusts*, 1 FRONTIERS IN ECOLOGY & THE ENV'T 181 (2003) (arguing that biological soil crusts, dominated by cyanobacteria, lichens and mosses, stabilize desert soil but are vulnerable to climate change and disturbance and recover very slowly).

[213] Jones et al., *supra* note 208, at 1950; EDWARD O. WILSON, THE FUTURE OF LIFE 110 (2002). For a recent review of the ecological impact of ecosystem engineers, see Jeffrey A. Crooks, *Characterizing Ecosystem-level Consequences of Biological Invasions: the Role of Ecosystem Engineers*, 97 OIKOS 153, 154-61 (2002).

[214] Mark A. Michael, *How to Interfere with Nature*, 23 ENVTL. ETHICS 135, 144-45 (2001) (rejecting the distinction that humans are different from all other living things on moral grounds).

[215] Daniel Simberloff, *Flagships, Umbrellas and Keystones: Is Single-Species Management Passé in the Landscape Era?*, 83 BIOLOGICAL CONSERVATION 247,

becomes important when ecological systems are invaded by new species, and native species that formerly played minor roles in their communities may become keystones by controlling the spread of invasion.[216] Ecologists recognize, however, that the identification of keystone species may be difficult because a species may be a keystone in one environment but not in another.[217] There appear to be no generally recognized rules for defining a keystone species.[218] Some ecological systems, particularly those characterized by high species richness, do not appear to have keystone species.[219] And some conservation biologists worry that too much reliance on the idea of keystone species may encourage the view that other species are redundant.[220]

iii. *Indicator species*

An indicator species is any species whose condition is indicative of the health of the ecological system.[221] Tulane University wildlife law expert Oliver Houck, in his extensive review of the actual operation of programs designed to protect

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254-55 (1998). *See also* Power et al., *supra* note 195, at 617 (noting utility of keystone species concept for managers). At present, the ESA provides no special protection for keystone or other focal species. Doremus, *Biological Diversity*, *supra* note 9, at 306-08 ("[S]pecies' keystone or indicator status is not considered in making listing decisions.").

[216] Robert P. Creed, Jr., *Is There a New Keystone Species in North American Lakes and Rivers?*, 91 OIKOS 405, 405 (2000).

[217] Power et al., *supra* note 195, at 614 (noting that definitions of keystone species are often context-dependent). *See also* WILSON, *supra* note 57, at 164-68 (noting that keystone species are identified only occasionally).

[218] "There is no consensus on what to measure as an indicator of the importance of a species to an ecosystem, nor does such a consensus seem likely." William Bond, *Keystone Species: Hunting the Snark?*, 292 SCI. 63, 64 (2001). For examples of the wide variety of kinds of species that have been characterized as keystones in particular situations, see W. J. Bond, *Keystone Species*, *in* BIODIVERSITY AND ECOSYSTEM FUNCTION 237, 237-45 (Ernst-Detlef Schulze & Harold A. Mooney, eds., 1994). Some ecologists have advocated a quite restrictive definition, but there appears to be no consensus on this question. Robert D. Davic, *Ecological Dominants vs. Keystone Species: A Call for Reason*, 4 CONSERVATION ECOLOGY 1 (2000).

[219] *See* Jason E. Tanner et al., *Species Coexistence, Keystone Species, and Succession: A Sensitivity Analysis*, 75 ECOLOGY 2204, 2217 (1994).

[220] *See* BOTKIN, *supra* note 193, at 287-89 (arguing that redundancy is more important than the existence of keystone species). *See* discussion at notes 371-385 *infra*.

[221] Ruhl, *supra* note 26, at 591.

biodiversity, concluded that the use of indicator species (including umbrella and keystone species) not only works, but is the only method that works.[222] He argues that indicator species are "as far as science can go" in producing specifics about how much of an identified ecosystem must remain:

> [Indicator species] remove the impossible factor from the equation: the ecosystem of human beings. Determining the essential minima of the sage shrub community of coastal California based on the gnatcatcher and other indicators is indeed difficult, and at times will be open to legitimate scientific challenge; but it is at least possible. Determining, on the other hand, what a "desired" ecosystem of coastal California should look like given what we have already done to it and are going to continue to do as fast as we can is not, in any legal sense, remotely possible. Once you put humans into the baseline, the standards disappear into a smudge of "multiple use," "optimal yield," and "people-are-part-of-ecosystems" rhetoric of the emerging and highly political federal process.[223]

Biologists seem to be less comfortable with the concept, pointing out that the use of indicator species to predict biodiversity "may prove to be impossible with any degree of rigor."[224] The use of indicator species has been criticized because it assumes a static view of ecological systems, ignoring the difficulty of predicting which species will be indicators in future stages of a changing environment.[225] In any given situation, it is difficult to determine whether any particular species is an "indicator species" until a change in the abundance of the species takes place.[226]

Another frequent criticism is that scientists or administrators select species as indicators because they happen to be familiar with the species.[227] The United States Forest Service's use of this practice has been criticized as a misinterpretation of the protection

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[222] Oliver A. Houck, *On the Law of Biodiversity and Ecosystem Management*, 81 MINN. L. REV. 869, 976 (1997).

[223] *Id*. at 976-77.

[224] John H. Lawton & Kevin J. Gaston, *Indicator Species*, *in* 3 ENCYCLOPEDIA OF BIODIVERSITY 437, 450 (Simon A. Levin ed., 2001) (referring to utility of indicator species in predicting diversity of unstudied taxa).

[225] J. B. Ruhl, *Thinking of Environmental Law as a Complex Environmental System*, 34 HOUS. L. REV. 933, 971-73 (1997).

[226] Dale et al., *supra* note 174, at 650.

[227] Pearson, *supra* note 175, at 76.

of biodiversity.[228] If rare species are selected as indicators, all the attention may get focused on the rare species and not on what it is supposedly indicating.[229]

Microbiologists increasingly point out that the kinds of organisms that they study may be playing more important indicator roles than more easily visible species,[230] and that organisms that we label "pests" and "pathogens" may actually be making important contributions to biodiversity.[231] As one research team writes, "It is highly likely that indigenous pathogens have been key determinants of plant community structure throughout history, and that this should be seen as a natural process."[232]

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[228] R. EDWARD GRUMBINE, GHOST BEARS: EXPLORING THE BIODIVERSITY CRISIS 106-09 (1992). GOBLE & FREYFOGLE, *supra* note 113, at 1388 ("By selecting species that thrive in and around timber harvest areas the Forest Service can more easily justify continued harvests; by selecting species that are disturbed by harvesting (or other intensive human activities), it can accomplish the opposite result."); Jack J. Lennon et al., *Contribution of Rarity and Commonness to Patterns of Species Richness*, 7 ECOLOGY LETTERS 81, 86 (2004) ("It is likely that a more accurate indication of the pattern of species richness for an entire group will be made by recording the distributions of common rather than rare species.").

[229] Pearson, *supra* note 175, at 76. On the other hand, the use of common species as indicators may not provide good predictability for rarer species. Patricia N. Manley et al., *Evaluation of a Multiple-Species Approach to Monitoring Species at the Ecoregional Scale*, 14 ECOLOGY 296 (2004) (finding that multiple-species monitoring adequately detects terrestrial vertebrates other than rare or endemic species or species of concern).

[230] Diana H. Wall and John C. Moore, *Interactions Underground*, 49 BIOSCIENCE 109 (1999) (stating that soil microbes are in mutualistic relationships with dominant plant species in all mature terrestrial ecosystems); Ching-Hong Yang et al., *Microbial Phyllosphere Populations are More Complex than Previously Realized*, 98 PROC. NAT'L ACAD. SCI. 3889, 3889 (2001) (describing how analysis of bacteria on plant leaves shows many more species of bacteria than realized by earlier culture-based methods). *See also* NAT'L RESEARCH COUNCIL, *supra* note 55, at 25; Thompson et al., *supra* note 64, at 16 (suggesting that the function of ecological communities depends heavily on little-studied hidden players, such as microbes, fungi, and soil invertebrates).

[231] Egbert Giles Leigh Jr., *Social Conflict, Biological Ignorance, and Trying to Agree which Species Are Expendable*, *in* THE IMPORTANCE OF SPECIES 239, 250-53 (Peter Kareiva & Simon A. Levin eds., 2003). *See also* Victor Smetacek, *The Ocean's Veil*, 419 NATURE 565 (2002) (stating ocean bacteria and other microbes are kept in check by "the double lock of predators and pathogens.").

[232] David R. Given et al., *Plant Conservation and Biodiversity: The Place of Microorganisms*, *in* MICROORGANISMS IN PLANT CONSERVATION AND BIODIVERSITY 1, 11 (K. Sivasithamparam et al. eds., 2002). *See also* S. Cleaveland et al., *The role of Pathogens in Biological Conservation*, *in* THE ECOLOGY OF WILDLIFE DISEASES 139, 141 (Peter J. Hudson et al. eds., 2002).

Since pathogens that cause high mortality cannot persist in small

**PUZZLE #3:**
**CAN SCIENTIFIC CRITERIA BE DEVELOPED FOR DESIGNATING FOCAL SPECIES TO SERVE AS PROXIES FOR BIODIVERSITY?**

b. *Unique species*

Although by definition each species is unique, some species are more distinctly different from any other species than others. Should a high degree of such difference give a species particular importance? This issue can be raised at both the local and the global level.

Biologists have debated local biodiversity by raising questions such as whether a local assemblage of two closely related butterflies is as diverse as an assemblage of a species of butterfly and a species of hoverfly,[233] or whether a community of five grass species is less diverse than a community of a single grass plus a daisy?[234] But the issue assumes more importance at the global level. Are there some categories of species that play more important roles in the world's biological diversity because of the greater or lesser distance of their relationship with most other species?[235]

Taxonomists use methods based on DNA analysis and observed morphological differences to create family trees for species.[236] They would certainly agree that a species that is the only remaining representative of a particular genus would be more unusual than a species in a genus that contains hundreds or

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> populations, it is the generalist pathogens as opposed to the host-specific pathogens that present the most serious extinction risks. Pathogens maintained in relatively common species might cause population extinction in threatened species when they "spill over" into threatened hosts.

*Id*.

[233] Gaston, *supra* note 170, at 77.

[234] Ernst-Detlef Schulze & Harold A. Mooney, *Ecosystem Function of Biodiversity: A Summary*, *in* BIODIVERSITY AND ECOSYSTEM FUNCTION 497, 504 (Ernst-Detlef Schulze & Harold A. Mooney eds., 1994).

[235] *See* Jepson & Canney, *supra* note 177, at 225.

[236] *See* discussion at notes 314-326 *infra*. For examples see Peter Cotgreave & Mark Pagel, *Predicting and Understanding Rarity: The Comparative Approach*, *in* THE BIOLOGY OF RARITY: CAUSES AND CONSEQUENCES OF RARE-COMMON DIFFERENCES 237, 239 (William E. Kunin & Kevin J. Gaston eds., 1997) (categorizing relative distinctiveness of 559 species of Australian birds in a family level phylogenetic tree).

thousands of species.[237] A famous example among taxonomists is the tuatara, which looks much like an iguana but is found only on a few islands offshore of New Zealand.[238] There are two or three species of tuatara, and they are the last living members of the order Sphenodontida, most of whose members lived 200 million years ago.[239] What degree of priority, if any, should protection of the tuatara receive? Robert May poses the question this way:

> At one democratic extreme, we could regard all species as equally important, each a unique evolutionary product; in this view, the tuatara is no more important than any other among the roughly 6000 species of reptiles. At the opposite extreme, we might give equal weight to each "sister group" in the phylogenetic tree of reptiles; on this basis, the two species of tuatara would be weighted equally with the sum of all 6000 other reptile species.[240]

On the other hand, some biologists have argued exactly the opposite, claiming that species that are closely related to other recently diverged species have the most potential for creating diversity.[241] Under this theory, newly emerged, closely related

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[237] Quentin D. Wheeler, *Systematics and Biodiversity: Politics at Higher Levels*, *in* BIOSCIENCE S-21, S-24 (Science & Biodiversity Policy Supp. 1995).

[238] NOEL SIMON, NATURE IN DANGER: THREATENED HABITATS AND SPECIES 193-95 (1995). Recently scientists have translocated a population of tuatara to another island off the New Zealand coast, but because the species is late-maturing and slow to reproduce it is not certain whether the population will become firmly established. Nicola J. Nelson et al., *Establishing a New Wild Population of Tuatara* (Sphenodon guntheri), 16 CONSERVATION BIOLOGY 887, 888 (2002).

[239] The other lizards are members of a different order, Squamata. PERLMAN & ADELSON, *supra* note 13, at 25. The Tuatara has been given legal protection in New Zealand since 1895, but the legislation assumed that all the Tuatara were a single species. WINSTON, *supra* note 148, at 242. Only in 1990 did phylogenetic analysis discover that there were actually two species, and at that time one of the two species was down to a population of less than 300 individuals. *Id*.

[240] May, *supra* note 50, at 17. May goes on to discuss various proposals that have been made to assign priorities based on relative distances between species on the phylogenetic "tree," but concludes that such assignments must await better quantification of such distances. *Id*. at 17-18. *See also* Robert M. May, *Taxonomy as Destiny*, 347 NATURE 129, 130 (1990) (arguing for the need to include taxonomic distinctiveness in the "calculus of biodiversity"). The same reasoning might suggest that only one of the two species of tuatara needs to be preserved, except that both populations are so small that they are considered endangered. Daniel P. Faith, *Conservation Evaluation and Phylogenetic Diversity*, 61 BIOLOGICAL CONSERVATION 1, 8 (1992).

[241] Kaneko & Yomo, *supra* note 158, at 345 (noting that organisms emerging as new species have a higher potential to produce genetic variability than "living

species are worthy of most protection because they reflect evolutionary processes that will create future biodiversity. When there are a great number of closely related species, biologists suggest that further species are likely to evolve within the same taxa if all the species are protected. "If the goal is to foster future evolutionary radiation, then it may make more sense to protect rapidly diversifying lineages (despite their recent common ancestry) as opposed to lineages that are more evolutionary inert."[242] Such a strategy would treat genetic uniqueness as a disfavored trait if the species was thought to be "relict" from an evolutionary perspective—a relic from an earlier era that would be unlikely to produce new species through evolution.[243] It would "distinguish 'cradles of diversity' (where diversity is generated) from 'museums' (where it persists)."[244]

The ESA has been criticized both for its failure to use uniqueness as a criterion for protecting species[245] and for its failure to consider evolutionary processes.[246] But is either of these approaches consistent with nonequilibrium ecology, which puts all species on an equal footing? In a world prone to disturbance who knows which species will become important?[247]

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fossils"). *See also* Terry L. Erwin, *An Evolutionary Basis for Conservation Strategies*, 253 SCI. 750, 752 (1991). "Conservation thinking is increasingly switching from preservation of the pattern of biodiversity to preservation of the processes that have generated the pattern." Georgina M. Mace et al., *Preserving the Tree of Life*, 300 SCI. 1707, 1708-09 (2003).

242 Ruckleshaus et al., *supra* note 116, at 676. *See also* Nagle, *supra* note 201, at 1256; Michael L. McKinney, *Biodiversity Dynamics: Niche Preemption and Saturation in Diversity Equilibria*, *in* BIODIVERSITY DYNAMICS: TURNOVER OF POPULATIONS, TAXA, AND COMMUNITIES 1, 15-16 (Michael L. McKinney & James A. Drake eds., 1998) ("[D]ifferences in extinction proneness among taxa should be a focus of conservation efforts. . . ."); Bruford, *supra* note 148, at 4. On the issue of whether increases in biodiversity through speciation are desirable, see the discussion at notes 555-576 *infra*.

243 A relict organism is one that has survived while other related ones have become extinct. A DICTIONARY OF ECOLOGY 346 (Michael Allaby ed., 2d ed. 1998).

244 Mace et al., *supra* note 241, at 1709.

245 Doremus, *Biological Diversity*, *supra* note 9, at 311.

246 Mace et al., *supra* note 241, at 1708.

247 Peggy L. Fiedler et al., *The Paradigm Shift in Ecology and Its Implications*, *in* THE ECOLOGICAL BASIS OF CONSERVATION: HETEROGENEITY, ECOSYSTEMS, AND BIODIVERSITY 83, 87-88 (Steward Pickett et al. eds., 1997). Mace et al., *supra* note 241, at 1709 (suggesting that the history of life has many examples of major radiations of species with unprepossessing origins).

c. *Sibling species*

At the opposite end of the spectrum from unique species are "sibling species" (also known as "cryptic species"), organisms that appear identical to us but not to themselves. Humans have traditionally tended to draw distinctions among different species based on their characteristics as perceived by our senses of sight and hearing. We assume that two organisms that look and sound the same to us are both members of the same species. But other organisms have their own sensory mechanisms that may not rely so extensively on sight and hearing.[248] Many different types of animals orient themselves by relation to the earth's magnetic field.[249] For example, salmon are believed to return to the place they were born through an intricate combination of magnetic detection, solar navigation, and olfactory clues.[250]

Biologists are increasingly finding groups of animals that appear identical in the field but diverge in habitat, life history, or chemical recognition systems.[251] For example, eighteen distinct new species were recognized in what were formerly thought to be two species of deepwater crab, and a common type of reef-building coral was found to consist of four sibling species.[252] In the past twenty-five years, more than 100 new fresh water fish species have been described, many on the basis of genetic traits revealed only through the use of modern molecular techniques.[253] NMFS already uses Evolutionarily Significant Units (ESUs)[254] to

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[248] For a very readable survey of the wide variety of animal sensory mechanisms, see HOWARD C. HUGHES, SENSORY EXOTICA: A WORLD BEYOND HUMAN EXPERIENCE (1999).

[249] Kathryn Brown, *Animal Magnetism Guides Migration*, 294 SCI. 283 (2001).

[250] Michael H. Schiewe & Peter Karieva, *Salmon*, *in* 5 ENCYCLOPEDIA OF BIODIVERSITY 233, 238 (Simon A. Levin ed., 2001).

[251] May, *supra* note 50, at 17; ERNST MAYR, THIS IS BIOLOGY 128 (1997) (stating that sibling species have been found in almost all higher taxa of animals, and they also occur among plants); Nancy Knowlton, *Sibling Species in the Sea*, 24 ANN. REV. ECOLOGY SYS. 189 (1993).

[252] Marjorie L. Reaka-Kudla, *The Global Biodiversity of Coral Reefs: A Comparison with Rain Forests*, *in* BIODIVERSITY II: UNDERSTANDING AND PROTECTING OUR BIOLOGICAL RESOURCES 83, 95 (Marjorie L. Reaka-Kudla et al. eds., 1997). *See also* Knowlton, *supra* note 251, at 203 (discussing sibling corals).

[253] Stein et al., *supra* note 86, at 61. *See also* MINELLI, *supra* note 145, at 210-11.

[254] For a discussion of the protocols for designating ESUs, see DANIEL R.

classify salmon because the mixing of hatchery fish and wild fish has reduced the relevance of traditional species concepts.[255] In other cases, genetic analysis has indicated that some species that had been thought to be distinct are likely to be just separate races of the same species.[256]

Should we group sibling species into a single category for protection purposes unless a convenient form of identification in the field is feasible?[257] Can we hope to find practical ways of protecting sibling species if we aren't able to distinguish them in the field?

## PUZZLE #4: SHOULD WE TREAT SPECIES DIFFERENTLY DEPENDING ON THE EXTENT TO WHICH THEY HAVE AN EVOLUTIONARY HISTORY OR HIDDEN TRAITS THAT ARE SIMILAR TO OTHER SPECIES?

d. *Endemic vs. peripheral species*

Any species that is found only in one particular area is "endemic" to that area. Some biologists argue that programs to

BROOKS & DEBORAH A. MCLENNAN, THE NATURE OF DIVERSITY: AN EVOLUTIONARY VOYAGE OF DISCOVERY 533-42 (2002). *But see* Bruford, *supra* note 148, at 10 (stating that the use of single genetic markers, such as mtDNA alleles, to identify ESUs creates a great multiplicity of ESUs, because such factors can diverge rapidly due to fragmentation, genetic bottlenecks, and drift. In the absence of guidelines for prioritization by resource managers, such "over-diagnosis could therefore be regarded as counterproductive."). *See also* Doremus, *Endangered Species*, *supra* note 9, at 1109-11 (criticizing overemphasis on genetic distinctness).

[255] Ruckleshaus et al., *supra* note 116, at 667. *See also* Master et al., *supra* note 199, at 106 (noting use of ESUs for salmonid fish); Kate Geoffroy & Thomas Doyle, *Listing Distinct Population Segments of Endangered Species: Has It Gone Too Far?*, 16 NAT. RESOURCES & ENV'T 82, 87 (2001); Alsea Valley Alliance v. Evans, 161 F. Supp 2d 1154, 1162-63 (D. Ore. 2001) (holding NMFS lacked statutory authority to exclude hatchery salmon from ESU), *appeals dismissed*, 358 F.3d 1181 (9th Cir. 2004) (holding environmental intervenor-appellants could not appeal because decision not final as to them).

[256] AVISE, *supra* note 125, at 204. Some biologists doubt whether phylogenetics will successfully reveal sibling species. M. F. Claridge et al., *Practical Approaches to Species Concepts for Living Organisms*, *in* SPECIES: THE UNITS OF BIODIVERSITY 1, 10 (M. F. Claridge et al. eds., 1997).

[257] In some cases, the differences among sibling species can be identified in the field by behavioral patterns, such as mating behavior, even though a visual examination of museum specimens could not make a distinction. WINSTON, *supra* note 148, at 61.

protect biodiversity should give priority to endemic species.[258] Endemics now receive no greater protection under the ESA than any other species,[259] although statistically the endemic species are more likely to go extinct.[260] The legal criteria of the ESA look only at the issue of whether a species is facing extinction within the United States, regardless of how common or rare it is elsewhere.[261]

The result is that the ESA protects some species that are rare in the United States even though they are common species in other parts of the world.[262] Such species that happen to extend into the United States at the edge of their range are known as "peripheral species."[263] In some cases the populations in the United States are reproductively isolated from those in other countries,[264] but in other cases the populations adjoin and interact with populations in Mexico, Canada, or the oceans.[265] To the extent that the statute

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[258] *See* BROOKS & MCLENNAN, *supra* note 254, at 545-46.

[259] *See, e.g.*, Doremus, *Endangered Species*, *supra* note 9, at 1087-89. In the administration of the ESA, of course, it is possible that endemic species may receive special attention informally. *See* GOBLE & FREYFOGLE, *supra* note 113, at 1194-95 (FWS seeks flexibility in managing at-risk species).

[260] M. Philip Nott & Stuart L. Pimm, *The Evaluation of Biodiversity as a Target for Conservation*, *in* THE ECOLOGICAL BASIS OF CONSERVATION: HETEROGENEITY, ECOSYSTEMS, AND BIODIVERSITY 125, 126 (Steward Pickett et al. eds., 1997); STUART L. PIMM, THE WORLD ACCORDING TO PIMM: A SCIENTIST AUDITS THE EARTH 223-28 (2001). Almost half of the vertebrate species endemic to the United States are listed by The Nature Conservancy as species of conservation concern. Master et al., *supra* note 199, at 103.

[261] Defenders of Wildlife v. Norton, 258 F.3d 1136, 1143 (9th Cir. 2001); United States v. McKittrick, 142 F.3d 1170, 1172 (9th Cir. 1998).

[262] *E.g.*, United States v. McKittrick, 143 F.3d at 1172.

[263] Master et al., *supra* note 199, at 98-99.

[264] An example is the American Crocodile, listed as an endangered species in the United States, but with a range that includes "the southern tip of Florida, both the Atlantic and Pacific coasts of southern Mexico, Central America, and northern South America, as well as the Caribbean islands of Cuba, Jamaica, and Hispaniola. . . ." HARRY MESSEL ET AL., CROCODILES: AN ACTION PLAN FOR THEIR CONSERVATION 91 (1992).

[265] An example is the cactus ferruginous pygmy-owl, which is common in Mexico, Central and South America, but is a protected species in Arizona. A. Townsend Peterson, *Endangered Species and Peripheral Populations: Cause for Reflection*, 18 ENDANGERED SPECIES UPDATE 30, 30 (2001). For background on the listing of the species, see Christopher J. Basilevac, Note, *Understanding the Endangered Species Act: A Case Study of the Cactus Ferruginous Pygmy-owl in Arizona*, 43 ARIZ. L. REV. 173, 179-87 (2001). The ninth circuit court of appeals overturned the listing of the Arizona population of the owl because FWS had based its decision on presumed genetic differences between the Arizona

allows the agencies to list a species as threatened or endangered throughout "a significant portion of its range,"[266] the ESA appears to encourage listings of peripheral populations.[267]

Some biologists have questioned whether the United States government should be expending its resources on protecting peripheral populations of common species.[268] University of Toronto zoologists Daniel Brooks and Deborah McLennan argue that it is a mistake to emphasize preservation of areas on the periphery of the range of many species, even though such areas may have very high local biodiversity, because preservation of such an area may be counterproductive if it creates forced competition that "could lead to a rapidly cascading series of regional extinctions. . . ."[269] They argue that preference should be given to areas with concentrations of endemic species that are restricted to the particular area in question.[270]

Some biologists suggest that peripheral populations do deserve special attention.[271] A recent study of 245 species of

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population and the Mexican population but there was no evidence to support such differences. National Ass'n of Home Builders v. Norton, 340 F.3d 835, 847, 852 (9th Cir. 2003). For other examples, see Defenders of Wildlife v. Norton, 239 F. Supp. 2d 9 (D.D.C. 2002) (enjoining FWS from engaging in any ESA § 7 determinations until critical habitat for the Canada Lynx is designated, for the southernmost portions of its range); Tony Povilitis, *The Jaguar in the Southwest: Borderland or Borderline Conservation?*, 19 ENDANGERED SPECIES UPDATE 207 (2002) (arguing that jaguar survival in Mexico is linked to jaguar presence in the American Southwest).

266 16 U.S.C. §§ 1532(6), 1532(20) (2000).

267 *See generally Defenders of Wildlife*, 258 F.3d at 1136 (remanding to FWS to require determination whether separate populations of flat-tailed horned lizard are threatened). The case is discussed further in Linda C. Maranzana, Note, Defenders of Wildlife v. Norton: *A Closer Look at the "Significant Portion of Its Range" Concept*, 29 ECOLOGY L. Q. 263 (2002) (arguing that "significant portion of its range" should be interpreted alongside the ESA's definitions of "species").

268 *See, e.g.*, Peterson, *supra* note 265, at 30.

269 BROOKS & MCLENNAN, *supra* note 254, at 545.

270 *See id.* at 546; KEVIN J. GASTON & JOHN I. SPICER, BIODIVERSITY: AN INTRODUCTION 51-53 (1998); NAT'L RESEARCH COUNCIL, *supra* note 19, at 27.

271 *See* S. R. Beissinger et al., *Report of the AOU Conservation Committee on the Partners in Flight Species Prioritization Plan*, 117 THE AUK 549, 550, 554 (2000) (suggesting that isolated subspecies of widespread species may be evolutionary important). As early as 1936 Aldo Leopold referred to the "important problem of preserving the attenuated edges of species common at their respective centres. . . . That there are grizzlies in Alaska is no excuse for letting the species disappear from New Mexico." ALDO LEOPOLD, THREATENED SPECIES, *reprinted in* ALDO LEOPOLD'S WILDERNESS 193, 197 (David E. Brown

endangered birds and mammals suggests that in most cases the remaining individuals are found at the periphery of their original range, not at the core as had been expected.[272] Evolutionary biologists generally believe that a peripheral population of a species, if truly isolated from the main population, is often likely to evolve into a separate species.[273] In theory, therefore, isolated peripheral populations may be evolving into new endemic species and thus deserve special protection,[274] but empirical studies have not always found evidence of such evolutionary tendencies on the ground.[275]

**PUZZLE #5:**

**SHOULD WE GIVE PRIORITY TO LOCALLY ENDEMIC SPECIES AND LESSER PROTECTION TO PERIPHERAL POPULATIONS OF SPECIES THAT INTERACT WITH ABUNDANT POPULATIONS OF THE SAME SPECIES LIVING OUTSIDE THE UNITED STATES?**

4. *LINEAGE*

The arguments among biologists about the application of the Linnaean system of classification, discussed in the previous

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& Neil B. Carmony eds., 1990).

[272] R. Channell & M. V. Lomolino, *Dynamic Biogeography and the Conservation of Endangered Species*, 403 NATURE 84, 84-85 (2000). *But c.f.* Jon Paul Rodriguez, *Range Contraction in Declining North American Bird Populations*, 12 ECOLOGICAL APPLICATIONS 238, 238-39 (2002) (suggesting that conservation efforts should be concentrated in high abundance areas).

[273] Lawrence R. Heaney, *Dynamic Disequilibrium: A Long-Term Large-Scale Perspective on the Equilibrium Model of Island Biogeography*, 9 GLOBAL ECOLOGY & BIOGEOGRAPHY 59 (2000); Master et al., *supra* note 199, at 99. This process is commonly known as allopatric speciation. ROBERT A. WALLACE, BIOLOGY: THE WORLD OF LIFE 208 (5th ed. 1990). *See also* ERNST MAYR, WHAT EVOLUTION IS 176-80 (2002); text accompanying notes 560-562 *infra*.

[274] Sherwin & Moritz, *supra* note 58, at 33. Some studies suggest that species evolving from isolated populations may tend to suffer from inbreeding. Man Kyu Huh & Hong Wook Huh, *Genetic Diversity and Population Structure of* Juniperus rigida *(Cupressaceae) and* Juniperus coreana, 14 EVOLUTIONARY ECOLOGY 87, 95-96 (2000). Studies comparing the genetic variability of species at the core versus the periphery of their range have produced conflicting and inconclusive results. KEVIN J. GASTON, THE STRUCTURE AND DYNAMICS OF GEOGRAPHIC RANGES 60-64 (2003).

[275] Michael L. Rosenzweig & Mark V. Lomolino, *Who Gets the Short Bits of the Broken Stick?*, *in* THE BIOLOGY OF RARITY: CAUSES AND CONSEQUENCES OF RARE-COMMON DIFFERENCES 63, 72-75 (William E. Kunin & Kevin J. Gaston eds., 1997).

sections,[276] are less vitriolic than the argument about whether the entire Linnaean system needs to be replaced, a topic which will now be addressed.

One of the deep conflicts in the current debate concerns whether species should be categorized on their appearance or bioevolutionary profile. The Linnaean system has evolved over time from one that based its classification primarily on the appearance of organisms ("morphology") to one that primarily relied on the behavior of organisms, particularly reproductive behavior, and is now trying to integrate new genetic information about the evolutionary history of organisms ("phylogenetics").

a. *Morphological taxonomy*

Scientists of Linné's generation knew nothing of evolution or genetics.[277] They had inherited the philosophy of the great chain of being, which adhered to the view that God created and ranked all forms of life from the highest and most complex, man, down to the simplest and least significant.[278] Many theologians of the day thought this chain was a spectrum without branches in which each segment gradually blended into the others, thereby creating a hierarchical model for both nature and human society.[279]

Humans had long given names to different categories of plants and animals on the bases of the characteristics they could most easily understand—the external appearance and anatomy of the organism,[280] known to biologists as the organism's "morphology."[281] Naturalists of Linné's era typically collected plant and animal specimens from all over the world,[282] and the museums were filling up with such specimens.[283] This led to considerable pressure to adopt some internationally accepted system of classification.[284]

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[276] *See supra* text accompanying notes 173-232.
[277] COLIN TUDGE, THE VARIETY OF LIFE 23-26 (2000).
[278] BOWLER, *supra* note 165, at 157-59.
[279] *Id*. at 158.
[280] TUDGE, *supra* note 277, at 20-21.
[281] *Id*. at 23. *See also* MAYR, *supra* note 251, at 127-28.
[282] BOWLER, *supra* note 165, at 147.
[283] *Id*. at 141. The motive for much of this collecting was the search for medicines and other useful products. TUDGE, *supra* note 277, at 21.
[284] TUDGE, *supra* note 277, at 21-22.

Almost inevitably, therefore, classifiers were driven to use morphological characteristics as the primary basis for classification.[285] To some extent they were aware of the behavior and life history of the more familiar organisms,[286] or thought they were,[287] but in order to deal with the flood of specimens arriving from distant lands they needed to have criteria that could be applied to dried or preserved specimens in museums by people who had never seen the living organism.[288] The desire to be able to apply the system to extinct plants and animals also encouraged the use of criteria that emphasized bone structure or other hard structural elements that would be preserved as fossils, rather than soft elements that would decay rapidly.[289]

So, to put it simply, if it looked like a duck, it was a duck; if it was known to quack and fly south in the winter, that would increase the classifier's degree of confidence, but knowledge of the organism's behavior was not essential.[290] Taxonomists became very skilled in dissecting animals and using similarities in bone structure to identify species and classify them into an appropriate genus, order, and other subcategories.[291] Despite our newfound ability to second guess the early taxonomists by using behavioral and genetic analysis, what is remarkable is not the many mistakes they seem to have made but the much larger number of cases in which all of the techniques appear to agree.[292]

So until well into the twentieth century, the Linnaean system of classification relied primarily on sorting organisms according to

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[285] TUDGE, *supra* note 277, at 23.

[286] BOWLER, *supra* note 165, at 147. For example, Mark Catesby, the earliest systematic collector of North American organisms, sent sketches along with shipments of plant and animal specimens. HENRY SAVAGE JR., LOST HERITAGE 57-92 (1970).

[287] Linné and his followers incorporated some "folk taxonomy" based on the common beliefs in the community about which groups of animals or plants belonged together. MINELLI, *supra* note 145, at 210.

[288] Claridge et al., *supra* note 256, at 4.

[289] *See* BOWLER, *supra* note 165, at 177-78.

[290] Stewart H. Berlocher, *Origins: A Brief History of Research on Speciation*, *in* ENDLESS FORMS: SPECIES AND SPECIATION 1, 4 (Daniel J. Howard & Stewart H. Berlocher eds., 1998). *See also* MAYR, *supra* note 251, at 127 (stating that "different" meant differing in visible morphological features).

[291] BOWLER, *supra* note 165, at 252-55. *See also* SIMON SCHAMA, LANDSCAPE AND MEMORY 51 (1995) (noting that Linné was known to opine on species issues without ever seeing the live animal).

[292] MAYR, *supra* note 273, at 25-27; TUDGE, *supra* note 277, at 23.

the similarity of their morphological characteristics.[293] As the museums' examination of morphology became more accurate with improved techniques of observation and measurement, however, taxonomists often disagreed about the extent to which small variations in morphology should be the basis for classifying organisms as different species.[294] The two differing factions became known as the "lumpers" and the "splitters;" the former tend to group organisms having only minor variations as a single species, while the latter choose to separate them into many species on the basis of these small variations.[295]

The splitters made life very difficult for the naturalists working in the field, because minor variations often were undetectable until a corpse was examined in the museum.[296] One well-respected biologist proposed eighty-seven separate species of North American grizzly bear.[297] Besides, the field naturalists thought they had some knowledge that the museum taxonomists lacked—they knew something about the organism's behavior.[298]

b. *Reproductive isolation*

Of all the behavioral characteristics of organisms that could be observed in the field, many biologists thought the most critical was the means of reproduction.[299] Most known animals and many plants reproduced sexually, so that the young plants or animals inherited traits from two separate organisms.[300] Field biologists argued that by observing which organisms got together to reproduce they could identify the key characteristic that defined a species.[301]

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[293] Berlocher, *supra* note 290, at 5. TUDGE, *supra* note 277, at 46 ("Everything measurable was measured and compared, and the results analysed statistically. . . .").

[294] *See* BOWLER, *supra* note 165, at 147; Corliss, *supra* note 166, at 1065-66.

[295] SCOTT WEIDENSAUL, LIVING ON THE WIND: ACROSS THE HEMISPHERE WITH MIGRATORY BIRDS 166 (1999). For an example, see Pratt & Pratt, *supra* note 147, at 69-71.

[296] *See* Bock, *supra* note 163, at 1068-69.

[297] WEIDENSAUL, *supra* note 295, at 166.

[298] BOWLER, *supra* note 165, at 468. *See generally* ROBERT E. KOHLER, LANDSCAPES AND LABSCAPES: EXPLORING THE LAB-FIELD BORDER IN BIOLOGY (2002) (examining the dynamic between laboratory work and field work).

[299] Doremus, *Endangered Species*, *supra* note 9, at 1090-91.

[300] MAYR, *supra* note 251, at 129.

[301] Claridge et al., *supra* note 256, at 4-5 (stating that from an early time,

The famous Harvard biologist, Ernst Mayr, became the foremost proponent of this thesis, which became known as the "biological species concept."[302] Each species, he argued, was reproductively isolated; those organisms that would mate together should be classified as a single species, from which all others should be excluded, regardless of morphological similarity.[303] The use of behavioral characteristics tied in with the gradual acceptance of a "modern synthesis" of evolutionary biology, which emphasized that the evolution of morphological characteristics typically reflected changing behavioral patterns.[304]

The emphasis on reproductive isolation did present some problems. If similar-appearing groups were widely separated geographically, no one knew if they would interbreed in nature if brought together.[305] Taxonomists often felt forced to classify them as separate species even when it was possible that the organisms themselves would interbreed if given the opportunity.[306]

On the other hand, the switch to reproductive isolation criteria was particularly annoying to observers who had relied on morphological characteristics to differentiate species in the field, such as recreational birders, who often maintained life lists of the number of species they had observed, and were forced to trim their lists as ornithological committees became "lumpers," combining groups with differing appearances that interbred where their range intersected.[307]

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biologists in the natural history tradition, such as Darwin and Wallace, urged emphasis on biological reality in the field); CHARLES DARWIN, 2 THE VARIATION OF ANIMALS AND PLANTS UNDER DOMESTICATION 173 (1868) ("If . . . the blue and red flowered forms of the pimpernel [were] sterile when crossed, I presume that all the botanists who now maintain on various grounds that these two forms are merely fleeting varieties, would at once admit that they were specifically distinct.").

[302] Claridge et al., *supra* note 256, at 5.

[303] *Id*. at 5-6.

[304] Berlocher, *supra* note 290, at 6-9. *See* SPICER & GASTON, *supra* note 118, at 47-48 (noting that behavioral changes are important ways by which animals react to environmental stress).

[305] Claridge et al., *supra* note 256, at 8; MAYR, *supra* note 251, at 129-30. For an example, see B. Rosemary Grant & Peter R. Grant, *Lack of Premating Isolation at the Base of a Phylogenetic Tree*, 160 AM. NATURALIST 1, 1 (2002) (comparing interbreeding behavior of two lineages of warbler finches).

[306] *See* PIMM, *supra* note 260, at 188.

[307] WEIDENSAUL, *supra* note 295, at 166-67; Kevin D. Hill, The *Endangered Species Act: What Do We Mean by Species?*, 20 B. C. ENVTL. AFF. L. REV. 239, 251 (1993). For other examples of the difficulties in applying the concept of

Despite these complaints, reproductive isolation provided a solid, logical basis for defining many groups of organisms, and by the early 1960s the essence of Mayr's thesis dominated the entire field of biological systematics.[308] It was not long, however, before the rapidly expanding doctrine and technology of molecular biology had two dramatic effects on biological systematics: (1) it provided the tools to quicken discovery of microscopic organisms which often reproduced asexually and to which the idea of reproductive isolation was not applicable;[309] and (2) it enabled biologists to "trace the evolution of life in a swift and convincing manner."[310] The ability to trace evolutionary lineages reliably,[311] when combined with the growing agreement on a "modern synthesis" of evolutionary theory in the mid-twentieth century,[312] gave such lineages growing importance.[313]

c. *Phylogenetics*

"Phylogenetics" is the term for using genetic information to trace the evolutionary paths taken by particular organisms, and to measure the degree to which they share the same genetic material.[314] Modern techniques of molecular biology[315] allow

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reproductive isolation in practice, see Wilson, *supra* note 148, at 22, 26-27.

[308] Berlocher, *supra* note 290, at 8-9. *See also* Mayden, *supra* note 166, at 382 (noting that little has changed with regard to the "species problem" since Mayr's work in 1957).

[309] MARC ERESHEFSKY, THE POVERTY OF THE LINNAEAN HIERARCHY: A PHILOSOPHICAL STUDY OF BIOLOGICAL TAXONOMY 81-84, 230 (2001). Some biologists use a "cohesion species concept" for asexual organisms. *See* WINSTON, *supra* note 148, at 44-46. The awareness of the prevalence of asexual reproduction did not begin until technological improvements in microbiology took place. Darwin, for example, concluded "that it is a law of nature that organic beings shall not fertilize themselves for perpetuity." DARWIN, *supra* note 279, at 159.

[310] WILSON, *supra* note 213, at 15. Molecular techniques have had their most dramatic impact on the classification of very small organisms. *See* S. L. Baldauf, *The Deep Roots of Eukaryotes*, 300 SCI. 1703, 1703-05 (2003).

[311] Jonathan A. Eisen & Claire M. Fraser, *Phylogenomics: Intersection of Evolution and Genetics*, 300 SCI. 1706, 1706-07 (2003) (suggesting that evolutionary analysis improves genome studies).

[312] Berlocher, *supra* note 290, at 6-9.

[313] *See generally* Campbell O. Webb et al., *Phylogenies and Community Ecology*, 33 ANN. REV. ECOLOGICAL SYS. 475 (2002) (utilizing evolutionary relationships to inform community level study of ecology).

[314] Gittleman et al., *supra* note 42, at 54. For an example of the use of DNA analysis to trace the lineage of the Galapagos finches, see GRANT, *supra* note 63, at 423-29.

phylogeneticists to trace the ancestry of a species[316] and to measure the degree of genetic differences between members of populations, species, and even kingdoms of organisms.[317] Such measurements not only enable biologists to trace the "lineage" of an organism, but to estimate the time since the species evolved[318] and to map the differences among the species on the landscape.[319]

These advances in molecular biology called attention to a theory originally proposed in the mid-1960s by the German biologist Willi Hennig.[320] He proposed classifying all organisms solely by their evolutionary origins[321]–an idea that subsequently

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[315] The history of phylogenetics is summarized concisely in AVISE, *supra* note 125, at 33-36. For a somewhat more extensive summary of the tools of phylogenetic analysis, see BROOKS & MCLENNAN, *supra* note 254, at 23-99.

[316] Wilson, *supra* note 148, at 23-24. *See generally* MOLECULAR TOOLS FOR SCREENING BIODIVERSITY: PLANTS AND ANIMALS (Angela Karp et al. eds., 1998) (providing a description and assessment of the tools of molecular biology for screening and evaluation of biodiversity).

[317] Sogin & Hinkle, *supra* note 67, at 109, 110; NAT'L RESEARCH COUNCIL, *supra* note 55, at 25 ("Molecular tools for characterizing microbial diversity reveal vast stores of hidden diversity in oceans, sediments, and soils, including environments at extremes of temperature and pressure.").

[318] Brian S. Arbogast et al., *Estimating Divergence Times from Molecular Data on Phylogenetic and Population Genetic Timescales*, 33 ANN. REV. ECOLOGICAL SYS. 707, 708 (2002). *See also* J. J. Bull & H. A. Wichman, *Applied Evolution*, 32 ANN. REV. ECOLOGICAL SYS. 183, 185 (2001) (describing output of phylogenetic analysis as a "branching tree that represents the evolutionary history of the lineages being studied"). Phylogeneticists continue to refine the methodology for making such estimates. *See generally* John R. Stinchcombe et al., *Testing for Environmentally Induced Bias in Phenotypic Estimates of Natural Selection: Theory and Practice*, 160 AM. NATURALIST 511 (2002) (discussing environmentally-induced bias present in measurement of natural selection using phenotypic data).

[319] *See, e.g.*, Campbell O. Webb, *Exploring the Phylogenetic Structure of Ecological Communities: An Example from Rainforest Trees*, 156 AM. NATURALIST 145 (2000); Robert K. Wayne & Phillip A. Morin, *Conservation Genetics in the New Molecular Age*, 2 FRONTIERS IN ECOLOGY AND ENV'T 89 (2004). For example, a recent study identified the breeding areas of birds wintering in Texas by measuring stable isotope compositions taken from wintering birds' feathers and comparing them to typical compositions taken from breeding birds' feathers in the various breeding ranges of the species. Keith A. Hobson & Leonard I. Wassenaar, *Isotopic Delineation of North American Migratory Wildlife Populations: Loggerhead Shrikes*, 11 ECOLOGICAL APPLICATIONS 1545 (2001). *See also* Berlocher, *supra* note 290, at 8 (noting that study of geographic distribution of alleles allows deeper inferences of the history of population structure).

[320] *See generally* WILLI HENNIG, PHYLOGENETIC SYSTEMATICS (1966).

[321] Bock, *supra* note 163, at 1068. In its original form, Hennig's "cladistics" relied solely on morphological data to trace the evolutionary history and

became attractive to many molecular biologists.[322] Hennig's followers developed their own terminology: a group of organisms that share a common ancestor is called a "clade," and the science of classifying by clade is called "cladistics."[323]

During the last two decades of the twentieth century the technological ability to trace evolutionary descent of organisms advanced at a very rapid rate and is continuing to do so.[324] Without trying to chart these changes in any detail, the bottom line is that they gave many molecular biologists confidence that they could not only identify the evolutionary lineage of organisms, but that they could tell how long ago one category of organism split off from another.[325] For example, phylogenetic cladists tell us that the crocodilians (crocodiles, alligators, etc.) should be classified as more closely related to the birds than to the reptiles.[326]

Some biologists argue that the Linnaean idea of species has been "knocked aside" by our modern understanding of evolution.[327] Some proponents of alternative species concepts reject any reliance on morphology or reproductive isolation in

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relationships of various species, because in the 1960s molecular research was still in a very early stage; today systematists try to use both molecular and morphological data in assigning species to clades. IAN J. KITCHING ET AL., CLADISTICS: THE THEORY AND PRACTICE OF PARSIMONY ANALYSIS 102-08 (2d ed. 1998).

[322] Berlocher, *supra* note 290, at 10.

[323] OXFORD DICTIONARY OF BIOLOGY, *supra* note 18, at 125. Schisms have, of course, already developed among the cladists. *See* ERESHEFSKY, *supra* note 309, at 66-79. In addition, an opposing school of systematists, which argues that classifications should be based on characteristics derived from either morphology or observation, but not on evolution, has become known as "phenetics." OXFORD DICTIONARY OF BIOLOGY, *supra* note 18, at 453. *See also* Bock, *supra* note 163, at 1068.

[324] *See generally* Bull & Wichman, *supra* note 318, at 183-84 (describing phylogenetic analysis).

[325] Olaf R. P. Bininda-Emonds et al., *The (Super)tree of Life: Procedures, Problems and Prospects*, 33 ANN. REV. ECOLOGY & SYSTEMATICS 265 (2002) (noting that phylogenetic studies of hundreds of organisms are now routine); Michael J. Benton & Francisco J. Ayala, *Dating the Tree of Life*, 300 SCI. 1698, 1699-1700 (2003) (comparing molecular methods of determining ages of species with paleontological methods). This kind of time sequence is commonly called the "molecular clock." MAYR, *supra* note 273, at 37.

[326] *See* David M. Hillis & John J. Wiens, *Molecules versus Morphology in Systematics*, *in* PHYLOGENETIC ANALYSIS OF MORPHOLOGICAL DATA 1, 9-10 (John J. Wiens ed., 2000); JACK WILSON, BIOLOGICAL INDIVIDUALITY: THE IDENTITY AND PRESENCE OF LIVING ENTITIES 84 (1999).

[327] HEY, *supra* note 148, at 9; ERESHEFSKY, *supra* note 309, at 221-32.

favor of purely phylogenetic distinctions.[328] They argue that our whole system of classification is outmoded now that molecular identification of the relationship of organisms is possible.[329] They would reclassify organisms into groups of similar lineage using only the techniques of molecular biology.[330] Robert May suggests that in the future it is conceivable "that species identifications and subsequent taxonomic assignments will be based primarily on automated analyses of appropriately chosen DNA or other molecular material, keyed out against synoptic molecular cladograms."[331] Microbiologists tend to be particularly vociferous in seeking new means of classification of species for the categories of organisms they study.[332] Recreational birders—a strong species conservation lobby—are attracted by any system that would allow them to add new species to their life lists.[333]

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[328] *See* AVISE, *supra* note 125, at 295. *See also* Paul D. N. Hebert et al., *Biological Identifications Through DNA Barcodes*, 270 PROC. ROYAL SOC'Y LONDON, Series B 313 (2003) (advocating the use of cytochrome *c* oxidase I gene as a uniform taxonomic identification tool for all animal taxa, since it is an ancient and nearly universal gene that evolves rapidly).

[329] *See, e.g.*, Mallet, *supra* note 108 at 39; Faith, *supra* note 240, at 2-4; Joel Cracraft, *Species Concepts in Systematics and Conservation Biology–An Ornithological Viewpoint*, *in* SPECIES: THE UNITS OF BIODIVERSITY 325, 334 (M. F. Claridge et al. eds., 1997).

[330] *See* Diethard Tautz et al., *A Plea for DNA Taxonomy*, 18 TRENDS IN ECOLOGY & EVOLUTION 70 (2003); Don J. Melnick et al., *Conservation Genetics: Applying Molecular Methods to Maximize the Conservation of Taxonomic and Genetic Diversity*, *in* NATURE AND HUMAN SOCIETY: THE QUEST FOR A SUSTAINABLE WORLD 264, 265-67 (Peter H. Raven ed., 2000); Brent R. Riddle & David J. Hafner, *Species As Units of Analysis in Ecology and Biogeography: Time To Take the Blinders Off*, 8 GLOBAL ECOLOGY & BIOGEOGRAPHY 433 (1999); Sherwin & Moritz, *supra* note 58, at 29-30; R. H. Crozier & R. M. Kusmierski, *Genetic Distances and the Setting of Conservation Priorities*, *in* CONSERVATION GENETICS 227 (V. Loeschcke et al. eds., 1994).

[331] May, *supra* note 62, at 19. *See also* Edward O. Wilson, *The Encyclopedia of Life*, 18 TRENDS IN ECOLOGY AND EVOLUTION 77 (2003) (envisioning electronic database available worldwide encompassing all knowledge about all species).

[332] *See* Baldauf, *supra* note 310, at 1704; Brent D. Mishler, *Getting Rid of Species?*, *in* SPECIES: NEW INTERDISCIPLINARY ESSAYS 308, 312-14 (Robert A. Wilson ed., 1999); Jed Fuhrman, *Genetic Sequences From the Sea*, 424 NATURE 1001 (2003) (new evidence suggests diversity of marine bacteria is greater than previously thought). Jack Wilson goes further, and points out that the idea of "organism" may also need to be re-examined in the face of microbes that operate individually under some conditions but coalesce into multicellular organisms under other conditions. WILSON, *supra* note 326, at 97.

[333] Pratt & Pratt, *supra* note 147, at 79 ("[I]n the eyes of recreational birders, conservationists, and the general public, species status has almost magical

On the other hand, traditional species concepts have important defenders. Although they recognize that the present system has some problems, scientists argue that those problems are less serious than the problems that would be posed by a system solely based on phylogenetic cladistics.[334] Abandoning the Linnaean system would require a new organizing system that would communicate the taxon's rank and membership, and to date no agreement on such a system has been reached.[335] The critics of purely phylogenetic systems argue that descriptions of lineage are uneven across various taxa and geographic regions,[336] that differences between many different lineages cannot be identified in the field,[337] and that many reintroduction and habitat restoration techniques would be deemed unsuccessful if the result were deemed to have created "new" species.[338]

Other critics point out that phylogenetic analysis cannot be applied to most fossils, which would hamper the integration between biology and paleontology.[339] Others argue that phylogenetic theory is changing so fast that it may be a long time before it is ready to be the basis of a new system;[340] Holly

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properties. It is quite possible that many island species worldwide could become endangered or extinct without anyone noticing because birders ignored [bird types that] ornithologists called *sub*species.") (emphasis added).

[334] MAYR, *supra* note 251, at 143-46. *See also* Doremus, *Endangered Species*, *supra* note 9 at 1090-92, 1100-01 (stating that morphology is often the most readily-available evidence of evolutionary relationships, and although we should not apply reproductive isolation blindly, it remains important); Mace et al., *supra* note 241, at 1708 (stating that "saving accumulated phylogenetic branch lengths" lacks the resonance of "saving species").

[335] WINSTON, *supra* note 148, at 36.

[336] Douglas A. Kelt & James H. Brown, *Species as Units of Analysis in Ecology and Biogeography: Are the Blind Leading the Blind?*, 9 GLOBAL ECOLOGY AND BIOGEOGRAPHY 213 (2000).

[337] Gordon B. Corbet, *The Species in Mammals*, *in* SPECIES: THE UNITS OF BIODIVERSITY 341 (Michael F. Claridge et al. eds., 1997); Kelt & Brown, *supra* note 336, at 213. The need for further research in the relationship of phylogenetic differences to ecological processes is well recognized. Thompson et al., *supra* note 64, at 17-20.

[338] For an example, see Pratt & Pratt, *supra* note 147, at 79.

[339] Hillis & Wiens, *supra* note 326, at 4-6; Olivier Rieppel & Lance Grande, *Summary and Comments on Systematic Pattern and Evolutionary Process*, *in* INTERPRETING THE HIERARCHY OF NATURE: FROM SYSTEMATIC PATTERNS TO EVOLUTIONARY PROCESS THEORIES 227, 240-44 (Lance Grande & Olivier Rieppel eds., 1994). *See also* Benton & Ayala, *supra* note 325, at 1698.

[340] Beissinger et al., *supra* note 271, at 555. *See also* Shubin & Marshall, *supra* note 92, at 324.

Doremus says that "genetic comparisons suffer from the same lack of agreement on what characteristics matter to what extent that plagues morphological comparisons."[341]

d. *Pluralism*

There are many biologists (including some of those quoted above) who would like to see some blending of all of the various species concepts.[342] They emphasize that all of the concepts agree on the great majority of common species.[343] But unless the theoretical issues can be resolved, some scientists fear that policymakers will question whether it makes sense to emphasize species richness if they think that the scientific understanding of the concept of species is shaky.[344]

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[341] Doremus, *Endangered Species*, *supra* note 9, at 1133. In rejecting a petition to list the resident orca whales of Puget Sound, the NMFS conceded that the existing taxonomic classification of all orcas worldwide as a single species was no longer defensible in light of genetic evidence, but the agency relied on it anyway because there was widespread disagreement among taxonomists about how to reclassify the various populations. The District Court held that the agency's decision not to list the resident Puget Sound population violated the statutory requirement that such decisions be made on the best available science, and remanded it to the agency for further consideration. Center for Biological Diversity v. Lohn, 296 F.Supp.2d 1223 (W.D. Wash. 2003). Those industry groups that have been encouraging administrative law reforms to prevent agencies from relying on "bad science," *see, e.g.*, Wendy E. Wagner, *The 'Bad Science' Fiction: Reclaiming the Debate over the Role of Science in Public Health and Environmental Regulation*, 66 LAW & CONTEMP. PROB. 63, 70-71 (2003), may find that their reforms can cut both ways.

[342] Marc Ereshefsky, *Species and the Linnaean Hierarchy*, *in* SPECIES: NEW INTERDISCIPLINARY ESSAYS 285-86 (Robert A. Wilson ed., 1999); Robert E. Ricklefs, *A Comprehensive Framework for Global Patterns in Biodiversity*, *7 Ecology Letters* 1, 9 (2004); Robert K. Wayne & Phillip A. Morin, *Conservation Genetics in the New Molecular Age*, 2 FRONT. ECOL. ENVIRON. 89 (2004). Northwestern University philosopher David Hull, who has studied the species debate, points out that when one school of thought tends to dominate at a particular time they often become "monists," arguing that only their view should prevail, while the minority favor "pluralism." He believes the cladists are now the dominant view in scientific circles, and that it is non-cladists who are seeking pluralism. David L. Hull, *On the Plurality of Species: Questioning the Party Line*, *in* SPECIES: NEW INTERDISCIPLINARY ESSAYS 23, 28, 43 (Robert A. Wilson ed., 1999).

[343] *See* Elizabeth Pennisi, *Modernizing the Tree of Life*, 300 SCI. 1692, 1693 (2003). *See also* Pratt & Pratt, *supra* note 147, at 70-71.

[344] TAKACS, *supra* note 9, at 54. For example, despite the use of anatomical, physiological, ecological, behavioral, developmental, genetic, and genomic criteria, there is still little consensus among biologists about the identification of fish species in Lake Erie. Tracy Dobson et al., *Fish and Other Migrating Species*

Some biologists argue that new species concepts should only apply to specific classes of organisms, such as bacteria[345] or protists,[346] which do not fit neatly into traditional categories.[347]

Others favor using differing concepts independently and, where the concepts disagree, working out the conflicts on a case-by-case basis.[348] The Wildlife Conservation Society and the American Museum of Natural History are engaged in a joint program of "conservation genetics" that tries to combine phylogenetic and other taxonomic approaches to resolve practical needs for prioritizing groups of organisms for conservation purposes.[349]

Other leading biologists have called for a blending of phylogenetic and traditional methods, pointing out that if only phylogenetic methods are used, many isolated populations might have to be designated as separate species even though they might well interbreed if accessible to one another,[350] such as the seventeen new species of primates added to the list of threatened

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*in the Canada/U.S. Context*, 28 CANADA-U.S. L. J. 389, 400-01 (2002). *See also* Center for Biological Diversity v. Lohn, 296 F.Supp.2d 1223 (W.D. Wash. 2003).

345 Michael Goodfellow, *Towards a Practical Species Concept for Cultivable Bacteria*, *in* SPECIES: THE UNITS OF BIODIVERSITY 25 (M. F. Claridge et al. eds., 1997).

346 Patterson, *supra* note 82, at S96.

347 An International Code of Nomenclature for Bacteria has now been adopted and an International Committee on Taxonomy of Viruses is working on a system of nomenclature. WINSTON, *supra* note 148, at 13-14.

348 Claridge et al., *supra* note 256, at 13. *See also* Daniel P. Faith, *Phylogenetic Pattern and the Quantification of Organismal Biodiversity*, *in* BIODIVERSITY: MEASUREMENT AND ESTIMATION 45, 50-51 (D. L. Hawksworth ed., 1995) (proposing to combine phylogenetic and taxonomic approaches). For examples of some of the difficult issues posed by any pluralistic system, see generally INTERPRETING THE HIERARCHY OF NATURE: FROM SYSTEMATIC PATTERNS TO EVOLUTIONARY PROCESS THEORIES (Lance Grande & Olivier Rieppel eds., 1994).

349 The program investigates "conservation priorities at different hierarchical levels ranging from higher-level evolutionary relationships between taxa to individual relatedness within populations. In particular, scientists in the Conservation Genetics program have identified unique evolutionary lineages, new species, distinct populations, and important individual relationships." WILDLIFE CONSERVATION SOCIETY, CONSERVATION GENETICS, *at* http://wcs.org/home/science/genetics (last visited Feb. 3, 2004).

350 Claridge et al., *supra* note 256, at 10. For an interesting example, see Grant & Grant, *supra* note 305, at 1. *But see* Joel Cracraft, *supra* note 329, at 325 (favoring the use of phylogenetic analysis for that reason).

species.[351] These biologists also argue that the exclusive use of phylogenetic methods would fail to distinguish sibling species—those that are genetically identical but refuse to interbreed.[352] Conservation biologists increasingly see a greater need to protect the evolutionary processes that create biodiversity than to protect the present pattern of biodiversity, but they fear that the current state of phylogenetics is not adequate to provide the information on which to base such a dramatically different approach.[353]

**PUZZLE #6:**

**SHOULD WE CONTINUE TO UTILIZE THE TRADITIONAL CONCEPT OF SPECIES TO DETERMINE SPECIES RICHNESS AND SPECIES ENDANGERMENT, OR SHOULD WE SWITCH TO NEWER SYSTEMS OF CLASSIFYING ORGANISMS THAT EMPHASIZE SIMILARITY OF GENETIC LINEAGE?**

5. *Function*

Within many ecological systems, a number of different plants or animals seem to perform the same ecological functions by consuming common resources in a similar manner, and can be referred to as a "functional group"[354] or a "guild".[355] In a grassland, for example, there may be many kinds of small rodents that eat seeds. If the grassland is disturbed, the nature of the organisms that survive the disturbance may determine how the

351 Mace et al., *supra* note 241, at 1708.

352 Claridge et al., *supra* note 256, at 10.

353 Mace et al., *supra* note 241, at 1708-09.

354 *See generally* John C. Moore, *Diversity, Taxonomic versus Functional*, *in* 2 ENCYCLOPEDIA OF BIODIVERSITY 205 (Simon A. Levin ed., 2001). Ecologists use functional groups to simplify community complexity to manageable levels. Thompson et al., *supra* note 64, at 16.

355 CHARLES J. KREBS, ECOLOGY: THE EXPERIMENTAL ANALYSIS OF DISTRIBUTION AND ABUNDANCE 551-54 (4th ed. 1994); LEVIN, *supra* note 39, at 167 ("The concept of the guild recognizes a ubiquitous and fundamentally important aspect of ecological communities: their organization into functional groups of species that play similar roles, and hence interact strongly."). Some confusion may be created by the fact that the term guild is also sometimes applied to organisms that share the same environmental conditions even if they don't use the same resources. J. Bastow Wilson, *Guilds, Functional Types and Ecological Groups*, 86 OIKOS 507, 507-09 (1999). The term guild may be being used in so many different ways as to cause confusion. Daniel Simberloff & Tamar Dayan, *The Guild Concept and the Structure of Ecological Communities*, 22 ANN. REV. OF ECOLOGY AND SYSTEMATICS 115, 118 (1991).

grassland will reorganize itself.[356] Is it more important to ensure that the seed-eating function continues to be performed than to worry about which species of rodent performs it? And if so, does this suggest that some species are redundant and could be allowed to go extinct without affecting basic ecological processes? This section summarizes the debates about these controversial issues.[357]

a. *The role of functional groups*

Plants and animals have relatively few basic shapes and internal processes, in comparison to the total number of species, because there are a limited number of ecological functions that can be performed, and convergent evolution has led many taxonomically different species to evolve in similar directions to perform those functions.[358] For example, grazing animals have developed similar body types and behavior patterns despite having evolved from many different original taxa.[359] It can be argued that it is more important, from the standpoint of the maintenance of stable ecological processes, to have a diverse combination of functional groups of species than to have many species performing the same function.[360]

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[356] Peter S. White & Jonathan Harrod, *Disturbance and Diversity in a Landscape Context*, *in* WILDLIFE AND LANDSCAPE ECOLOGY: EFFECTS OF PATTERN AND SCALE 128, 135-38 (John A. Bissonette ed., 1997).

[357] Some science writers have characterized the debates among scientists over these issues as unusually vitriolic, Lila Guterman, *Have Ecologists Oversold Biodiversity?*, CHRON. OF HIGHER EDUC., Oct. 13, 2000, at A24, but debate is part of the normal process of scientific decision-making, Shahid Naeem et al., *Biodiversity and Ecosystem Functioning: The Emergence of a Synthetic Ecological Framework*, *in* BIODIVERSITY AND ECOSYSTEM FUNCTIONING: SYNTHESIS AND PERSPECTIVES 3, 9 (Michel Loreau et al. eds., 2002).

[358] Robert S. Steneck, *Functional Groups*, *in* 3 ENCYCLOPEDIA OF BIODIVERSITY 121, 122-24 (Simon A. Levin ed., 2001).

[359] W. J. Bond, *Functional Types for Predicting Changes in Biodiversity: A Case Study in Cape Fynbos, in* PLANT FUNCTIONAL TYPES: THEIR RELEVANCE TO ECOSYSTEM PROPERTIES AND GLOBAL CHANGE 174 (Thomas Michael Smith et al. eds., 1997) ("Strong character convergence is noise to a systematist but signal to an ecologist seeking functional interpretations of diversity."). Soil ecosystems seem to have especially high levels of functional redundancy. Peter C. de Ruiter et al., *Biodiversity and Stability in Soil Ecosystems: Patterns, Processes and the Effects of Disturbance*, *in* BIODIVERSITY AND ECOSYSTEM FUNCTIONING: SYNTHESIS AND PERSPECTIVES 102, 103-04 (Michel Loreau et al. eds., 2002).

[360] Brian H. Walker, *Biodiversity and Ecological Redundancy*, 6 CONSERVATION BIOLOGY 18 (1992). The pioneering study of this issue was Stuart L. Pimm, *The Complexity and Stability of Ecosystems,* 307 NATURE 321 (1984).

Some ecologists point out that because competition is more intense among organisms of the same functional group than among organisms of different functional groups, the ecological system can tolerate greater fluctuations within a single functional group than among different functional groups.[361] For example, one recent study of grassland-savannas concluded that, although species diversity did correlate with increased productivity, diversity of functional groups had an even more significant correlation to increased productivity.[362] Another study found that when the only member of a particular functional group of rodents was experimentally removed, another species eventually colonized the area and reinstituted the missing function.[363]

Interest in maintaining ecological functions has grown because of recognition that any area contains many interacting elements,[364] and "a focus on one or a few species or on biodiversity alone may lead to a neglect of important interactions or a failure to maintain the functional integrity of the

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[361] MICHAEL A. HUSTON, BIOLOGICAL DIVERSITY: THE COEXISTENCE OF SPECIES ON CHANGING LANDSCAPES 76-77 (1994). In some ecological systems, a few species may perform the bulk of the functions. H.A. Mooney, *Ecosystem Function of Biodiversity: The Basis of the Viewpoint*, *in* PLANT FUNCTIONAL TYPES 341, 347-48 (T.M. Smith et al. eds., 1997). *See also* Thomas M. Frost et al., *Species Compensation and Complementarity in Ecosystem Function*, *in* LINKING SPECIES AND ECOSYSTEMS 224 (Clive G. Jones and John H. Lawton eds., 1994).

[362] David Tilman et al., *The Influence of Functional Diversity and Composition on Ecosystem Processes*, 277 SCI. 1300 (1997). Other studies have found little correlation between diversity and productivity in particular situations. *See, e.g.*, Montserrat Vilà et al., *Does Tree Diversity Increase Wood Production in Pine Forests*, 135 OECOLOGIA 299 (2003); Samuel M. Scheiner & Sharon Jones, *Diversity, Productivity and Scale in Wisconsin Vegetation*, 4 EVOLUTIONARY ECOLOGY RESEARCH 1097 (2002) (difficult to explain relationship of diversity to productivity by any single theory); Shahid Naeem & Justin P. Wright, *Disentangling Biodiversity Effects on Ecosystem Functioning: Deriving Solutions to a Seemingly Unsurmountable Problem*, 6 ECOLOGY LETTERS 567 (2003) (critiquing methods of experimental modification of plant diversity in studies of the effect of biodiversity on ecological functions). A review of the literature found a "remarkable variety" of different productivity-biodiversity patterns. Tadashi Fukami & Peter J. Morin, 424 NATURE 423, 425 (2003).

[363] S. K. Morgan Ernest & James H. Brown, *Delayed Compensation for Missing Keystone Species by Colonization*, 292 SCI. 101, 103 (2001).

[364] *E.g.*, deLeij et al., *supra* note 74, at 249 (arguing that the benefits we obtain from soil microbes are created by the microbial community as a whole, not by any single species).

ecosystem."[365] Consequently, some biologists suggest that any definition of biodiversity should emphasize protection of the many ecological processes that involve a multiplicity of species.[366]

On the other hand, if functional processes become the primary focus of conservation, would species richness be severely threatened? One answer is, roughly, yes:

> If the current rate of tropical deforestation persists, we can imagine a future pantropical forest system composed of a few score of tree species, the same introduced insect, bird, and mammal species. Such a world might exhibit acceptable ecosystem processes yet contain a tiny fraction of current tropical biodiversity. Thus, although ecosystem processes may be a necessary target for conservation, they are not sufficient to conserve global biodiversity.[367]

The idea of using functional groups as a key component of the definition of biodiversity would depend on the ability to reach agreement on which functions are most important and which species are the key to those functions.[368] Any classification of

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[365] John A. Wiens, *The Emerging Role of Patchiness in Conservation Biology*, *in* THE ECOLOGICAL BASIS OF CONSERVATION: HETEROGENEITY, ECOSYSTEMS, AND BIODIVERSITY 93, 98 (Steward Pickett et al. eds., 1997). *See also* Brandon T. Bestelmayer et al., *Applying Species Diversity Theory to Land Management*, 13 ECOLOGICAL APPLICATIONS 1750 (2003).

> In analyzing biodiversity, it is a mistake to lump together species that differ widely in the kinds and scales of environmental variation to which they respond, rather than grouping sets of species that respond to environmental variation at similar scales. The selection of a predetermined spatial extent based on human perceptions complicates attempts to [identify] functional heterogeneity (which is defined by the responses of the organisms).

*Id.* (citation omitted).

[366] TAKACS, *supra* note 9, at 198-204. *See also* Doremus, *Biological Diversity*, *supra* note 9, at 282-85 (arguing that biological preservation efforts should focus on both life forms and life processes).

[367] M. Philip Nott & Stuart L. Pimm, *The Evaluation of Biodiversity as a Target for Conservation*, *in* THE ECOLOGICAL BASIS OF CONSERVATION: HETEROGENEITY, ECOSYSTEMS, AND BIODIVERSITY 125, 127 (Steward Pickett et al. eds., 1997). *See also* Michael E. Soulé, *Are Ecosystem Processes Enough?*, 6 Wild Earth 59 (1996). Some biologists think that diversity is not related to the complexity of the structure and processes of an ecological system "aside from the trivial fact that without any diversity there is no complexity." Shahid Naeem, *Complexity versus Diversity*, 1 ENCYCLOPEDIA OF BIODIVERSITY 831, 842 (Simon A. Levin ed., 2001). The history of these debates is discussed in Shahid Naeem, *Ecosystem Consequences of Biodiversity Loss: The Evolution of a Paradigm*, 83 ECOLOGY 1537 (2002).

[368] David U. Hooper et al., *Species Diversity, Functional Diversity, and*

functional groups is highly dependent on the particular function being studied; two species might be members of the same functional group for one function but not others.[369] For example, studies of plankton communities suggest that they are organized around a group of core species that are relatively insensitive to disturbance, but that they also contain a second group of species that fluctuate greatly in response to environmental disturbance. The latter group seems rare and expendable during normal conditions but may play important roles in reaction to disturbance.[370]

b. *Are any species redundant?*

Some people would carry the functional argument further by suggesting that certain species in a functional group should be considered redundant,[371] so that the local elimination of such species would have no significant effect on overall ecological system processes.[372] If we can be sure that other species will

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*Ecosystem Functioning*, I BIODIVERSITY AND ECOSYSTEM FUNCTIONING: SYNTHESIS AND PERSPECTIVES 195, 205-06 (Michel Loreau et al. eds., 2002) ("A common criticism of studying the effects of functional group diversity on ecosystem process is that the underlying rationale is circular. If the functional effect groups in question have been defined by their influence on an ecosystem process, then by definition, adding and removing these groups will alter that process.").

[369] S. E. Hobbie et al., *Resource Supply and Disturbance as Controls over Present and Future Plant Diversity*, *in* BIODIVERSITY AND ECOSYSTEM FUNCTION 385, 396 (Ernst-Detlev Schulze & H. A. Mooney eds., 1994) ("Clearly, the criteria and level of detail required to develop a functional group classification depend on the question posed and the state of our knowledge about the effects of individual species on ecosystem processes."); Amy J. Symstad & David Tilman, *Diversity Loss, Recruitment Limitation, and Ecosystem Functioning: Lessons Learned From a Removal Experiment*, 92 OIKOS 424, 432 (2001).

[370] Daniel E. Schindler et al., *Rarity and Functional Importance in a Phytoplankton Community*, *in* THE IMPORTANCE OF SPECIES 206, 218-20 (Peter Kareiva & Simon A. Levin eds., 2003). *See also* C. S. Holling et al., *Sustainability and Panarchies*, *in* PANARCHY: UNDERSTANDING TRANSFORMATIONS IN HUMAN AND NATURAL SYSTEMS 63, 84-85 (Lance H. Gunderson & C. S. Holling eds., 2002) (species that perform similar functions may have different responses to unanticipated environmental change).

[371] B. H. Walker, *Functional Types in Non-Equilibrium Ecosystems*, *in* PLANT FUNCTIONAL TYPES: THEIR RELEVANCE TO ECOSYSTEM PROPERTIES AND GLOBAL CHANGE 91 (Thomas Michael Smith et al. eds., 1997) ("Apparent species redundancy is observable in most ecosystems, at least with regard to the major ecosystem processes.").

[372] Holly Doremus, *The Rhetoric and Reality of Nature Protection: Toward a New Discourse*, 57 WASH. & LEE L. REV. 11, 47 (2000) ("Most ecosystem

perform the necessary functions equally well, should we assign the "redundant" species a low priority?[373]

One difficulty in lumping species into functional groups is that so many species are tightly linked to other species that perform different functions. For example, a particular plant may be pollinated by a number of different bird species, any one of which may perform the pollination function adequately. But one of the bird species may also perform a different function, such as keeping down the population of a certain insect that attacks the plant. Unless one studies all of the possible ecological functions of a species, it may be difficult to label it as redundant.[374]

Princeton ecologist Simon A. Levin argues that redundancy is an important value to protect for its own sake.[375] Species that may appear to be redundant at one point in time may turn out to be significant if environmental conditions change.[376] American

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functions are performed by multiple species. This functional redundancy means that a high proportion of species can be lost without precipitating a collapse."). *See also* L. B. Slobodkin, *The Good, the Bad, and the Reified*, 3 EVOLUTIONARY ECOLOGY RESEARCH 1, 5 (2001) (noting that the common perception that loss of species inevitably harms ecological processes is an overgeneralization). But a recent review of research on redundancy argues that this research contains implicit assumptions that systematically bias them toward falsely concluding that functional redundancy exists. Jordan S. Rosenfeld, *Functional Redundancy in Ecology and Conservation*, 98 OIKOS 156 (2002).

[373] As Holly Doremus puts it:

> Ecological redundancy is common. In many ecosystems, many species perform the same roles . . . . If we rely too much on the argument that the special economic value of nature justifies the costs of nature protection, even expanding economic value to include ecological services, we are likely to find ourselves with precious little protected nature.

Holly Doremus, *The Special Importance of Ordinary Places*, 23 ENVIRONS ENVTL. L. & POL'Y 3, 9-10 (2000).

[374] "Close linkages between species demonstrate the difficulty of lumping species into 'functional groups,' because the individual species within such a group may not be independent but tightly fixed to the existence of a species in quite another functional group." Schulze & Mooney, *supra* note 214, at 500-01 (citation omitted).

[375] LEVIN, *supra* note 39, at 202-03 (stating that redundancy, the functional substitutability of one species for another, is the equivalent of substitutability in economics).

[376] Ilkka Hanski & Daniel Simberloff, *The Metapopulation Approach: Its History, Conceptual Domain, and Application to Conservation*, *in* METAPOPULATION BIOLOGY: ECOLOGY GENETICS AND EVOLUTION 5, 10 (Ilkka Hanski & Michael E. Gilpin eds., 1997) (small patches may be a source of population growth even though the risk of local extinction is great); Ove Eriksson, *Functional Roles of Remnant Plant Populations in Communities and*

Chestnut trees were the dominant species in most forests in the Eastern United States until they were wiped out by a blight,[377] after which oaks, elms and other species, which had been less common, became the dominant species. These species were, in turn, threatened by other disease outbreaks.[378] After a disturbance, a species that formerly "appeared to be a small and functionally redundant part" of the ecosystem may often become dominant in the reconstruction,[379] while a formerly dominant species, which might have driven other species to extinction in a stable environment, might find its dominance subdued by new environmental conditions.[380] And if human-induced change is massive, remnant species may be unable to perform the functions of those that disappeared because the "community architecture once maintained by species interactions has also collapsed."[381]

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*Ecosystems*, 9 GLOBAL ECOLOGY & BIOGEOGRAPHY 443, 443 (2000) (remnant populations contribute to resilience of ecological systems).

[377] Rosenzweig & Lomolino, *supra* note 275, at 77.

[378] William Vogt, *Population Patterns and Movements*, *in* FUTURE ENVIRONMENTS OF NORTH AMERICA: TRANSFORMATION OF A CONTINENT 372, 386 (F. Fraser Darling & John P. Milton eds., 1966); Slobodkin, *supra* note 372, at 5-6.

[379] Judy L. Meyer, *Conserving Ecosystem Function*, *in* THE ECOLOGICAL BASIS OF CONSERVATION: HETEROGENEITY, ECOSYSTEMS, AND BIODIVERSITY 136, 140 (Steward Pickett et al. eds., 1997). *See also* Michio Kondoh, *Foraging Adaptation and the Relationship Between Food-Web Complexity and Stability*, 299 SCI. 1388 (2003) (complex food webs are better able to tolerate disturbance); C. P. H. Mulder et al., *Physical Stress and Diversity-Productivity Relationships: The Role of Positive Interactions*, 98 PROC. NAT'L ACAD. OF SCI. 6704 (2001) (environmental stress may create important functional roles for species that formerly seemed redundant). *See also* Richard J. Hobbs, *Managing Ecological Systems and Processes*, *in* ECOLOGICAL SCALE: THEORY AND APPLICATIONS 459, 476 (David L. Peterson & V. Thomas Parker eds., 1998).

[380] Dave A. Wardle & Wim H. Van der Putten, *Biodiversity, Ecosystem Functioning and Above-Ground-Below-Ground Linkages*, *in* BIODIVERSITY AND ECOSYSTEM FUNCTIONING: SYNTHESIS AND PERSPECTIVES 155 (Michel Loreau et al. eds., 2002); Clarence L. Lehman & David Tilman, *Competition in Spatial Habitats*, *in* SPATIAL ECOLOGY: THE ROLE OF SPACE IN POPULATION DYNAMICS AND INTERSPECIFIC INTERACTIONS 185, 190-94 (David Tilman & Peter Kareiva eds., 1997); Brian Walker et al., *Plant Attribute Diversity, Resilience, and Ecosystem Function*, 2 ECOSYSTEMS 95, 98, 110-11 (1999). *See generally* JONATHAN WEINER, THE BEAK OF THE FINCH (1995) (describing the work of Rosemary and Peter Grant, who has studied these kinds of changing dominance patterns in the finches of the Galapagos Islands over a series of changing climate conditions). A subsequent edition of Peter Grant's book on the finches updates their research. GRANT, *supra* note 63, at 435 (noting responses of finches to diverse and changing environmental conditions).

[381] Power et al., *supra* note 195, at 616. *See also* Giulio A. De Leo & Simon

Many conservation biologists fear that resource managers would use functional type to justify the elimination of individual species as long as another species appears to perform a similar ecological function.[382] Daniel Simberloff points out that a "second-growth forest of low diversity often has greater primary productivity than does the diverse old-growth forest it replaces. Is it therefore an acceptable substitute for the original?"[383] Most ecologists would argue that it is not, but the debate goes on.[384]

A panel of the National Research Council recently concluded that it "is clear that not all species are equally important, but little is known about the general extent to which ecologically similar species can substitute for each other in providing ecosystem services," and that a dedicated research effort to advance understanding of the relationship between diversity and ecological functions should be a high priority.[385]

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A. Levin, *The Multifaceted Aspects of Ecosystem Integrity*, 1 CONSERVATION ECOLOGY (1) 14 (1997), *available at* http://www.consecol.org/vol1/iss1/art3 (last visited Feb. 22, 2004) (arguing that advocates of a functional approach ignore the danger that the loss of diversity within functional groups may weaken the system's ability to respond to disturbance); J. H. Lawton & V. K. Brown, *Redundancy in Ecosystems*, *in* BIODIVERSITY AND ECOSYSTEM FUNCTION 266-67 (Ernst-Detlef Schulze & Harold A. Mooney eds., 1994) (variety of species within functional groups provides insurance against severe disruption); Robert S. Steneck, *supra* note 358, at 133 (functional groups can be composed of redundant species that perform essential ecosystem processes).

382 *See* Lee M. Talbot, *The Linkages between Ecology and Conservation*, *in* THE ECOLOGICAL BASIS OF CONSERVATION: HETEROGENEITY, ECOSYSTEMS, AND BIODIVERSITY 368, 373-74 (Steward Pickett et al. eds., 1997); Doremus, *supra* note 373, at 9; Wall & Moore, *supra* note 230, at 115 (noting that for microorganisms, mutualistic interactions between particular kinds of microorganisms and particular kinds of larger organisms are so species-specific that functional groups may not exist).

383 Simberloff, *supra* note 215, at 253.

384 For an example of a case in which arguments in favor of biodiversity prevailed over arguments in favor of productivity, see Florida Power Corp. v. Florida Dep't of Envtl. Reg., 638 So. 2d. 545, 561-62 (Fla. Dist. Ct. App. 1994).

385 NAT'L RESEARCH COUNCIL, *supra* note 55, at 23, 60. *See also* Shahid Naeem et al., *supra* note 357, at 11 ("There is still a debate over the relative or specific role of extrinsic factors, genetic, taxonomic, or functional diversity in ecosystem processes, but the scientific community should not ignore the issue because it is complex, confusing, or unclear."); Brian A. Maurer, *Is Biodiversity Important in Ecosystems?*, 84 ECOLOGY 1074 (2003) ("The unanswered question is whether our understanding is even capable of being deep enough to give us an adequate picture of the complexity inherent in ecological systems.").

**PUZZLE #7:**
**WHERE TWO OR MORE SPECIES APPEAR TO PERFORM THE SAME ECOLOGICAL FUNCTION, SHOULD WE FOCUS MORE ON ENSURING THAT THE FUNCTION IS PERFORMED, OR ON THE PROTECTION OF EACH INDIVIDUAL SPECIES?**

## B. *Too Little Diversity or Too Much?*

We are accustomed to thinking of biodiversity as a good thing that should be maximized. But within the boundaries of any given area, we often realize that too many species may threaten overall biodiversity. Frequently we wish we didn't have particular species in a local area because they are either exotics or hybrids.

### 1. *Native vs. exotic species*

Conservation biologists generally draw a distinction between native species and exotic species, with the native species to be protected and the exotics discouraged even if the result is less local biodiversity.[386] Thus, for example, invasions by exotic grasses in the grasslands of the western United States are widely seen as a destructive change in the ecological systems, even though species diversity may have been increased.[387] Invasive species have

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[386] Norman L. Christensen et al., *The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management*, 6 ECOLOGICAL APPLICATIONS 665, 673 (1996) ("The redistribution of species across the globe is one of the most significant human impacts on ecosystems. The negative consequences of exotic species . . . [are] testimony to the fact that the contribution of biological diversity to ecosystem functioning is not merely a matter of the number and kinds of species present."). The National Research Council recommended that a "native species diversity indicator" would be a useful measure of human impacts. NAT'L RESEARCH COUNCIL, ECOLOGICAL INDICATORS FOR THE NATION 80-81 (2000).

[387] DEBRA L. DONAHUE, THE WESTERN RANGE REVISITED: REMOVING LIVESTOCK FROM PUBLIC LANDS TO CONSERVE NATIVE BIODIVERSITY 119-20 (1999); David E. Ervin et al., *Agriculture and Environment: A New Strategic Vision*, 40 ENVIRONMENT No. 6, at 8, nn.37-38 (1998). Exotic annual grasses now dominate many California grasslands that were once dominated by native perennial grasses, but this is apparently not because the native species have been eliminated. The native species survive, though in reduced numbers, because they can utilize resources, such as deeper water, that the exotic annual grasses can't use. Dominance of exotics appears to reflect the fact that the native species never needed to develop strong dispersal capabilities in their original environment. Eric W. Seabloom et al., *Invasion, Competitive Dominance, and Resource Use by Exotic and Native California Grassland Species*, 100 PROC.

sometimes caused the complete extinction of native species, particularly on islands; the brown tree snake and the giant African snail have had devastating effects on certain islands in the Pacific.[388] Other invasive species have created substantial economic costs, such as the zebra mussel that has clogged water systems in many parts of the eastern United States.[389] Invasive species can also modify ecological processes in undesirable ways, as the salt cedar has by lowering the water table in riparian areas in the western United States.[390]

Mutual interactions among invading species may aggravate the degree of ecological modification,[391] as, for example, when an

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NAT'L ACAD. OF SCI. 13,384 (2003). Species from North America have sometimes invaded Europe with adverse effects on native species. An example is the gray squirrel from North America that has caused the rarity of the native red squirrel in England. H. A. Mooney & E. E. Cleland, *The Evolutionary Impact of Invasive Species*, 98 PROC. NAT'L ACAD. SCI. U.S. 5446, 5449 (2001); NANAKO SHIGESADA & KOHKICHI KAWASAKI, BIOLOGICAL INVASIONS: THEORY AND PRACTICE 109-14 (1997). Ecologists differ on whether the existing biodiversity of an area makes a difference in determining whether the area can resist invasions by other species. Some studies seem to suggest that it can, but not all ecologists agree. Jonathan M. Levine & Carla M. D'Antonio, *Elton Revisited: A Review of Evidence Linking Diversity and Invasibility*, 87 OIKOS 15, 15-16 (1999) (finding that field studies show no clear correlation between diversity and invasibility). *See also* Jocelyn Kaiser, *Does Biodiversity Help Fend Off Invaders?*, 288 SCI. 785, 785-86 (2000).

[388] MARK WILLIAMSON, BIOLOGICAL INVASIONS 145-49 (1996). Hundreds of local varieties of snail in Hawaii were eaten to extinction by the giant African snail, which was introduced to Hawaii in a futile attempt to control another introduced snail. PIMM, *supra* note 260, at 212. *See generally* Lance C. Osborne, *Release of Exotic Natural Enemies for Biological Control: A Case of Damned if We Do and Damned if We Don't?*, 18 J. LAND USE & ENVTL. L. 399 (2003). *See also* Dennis J. O'Dowd et al., *Invasional "Meltdown" on an Oceanic Island*, 6 ECOLOGY LETTERS 812 (2003) (describing collapse of ecological functions on Christmas Island following ant invasion that was aided by scale insects associated with the invading ants).

[389] WILLIAMSON, *supra* note 388, at 142-43. One group of authors nominates four species as the most harmful invaders: (1) the Nile Perch; (2) *Englandina rosea*, a predatory snail; (3) the zebra mussel; and (4) the Argentine ant. Michael D. Collins et al., *Species-Area Curves, Homogenization, and the Loss of Global dDiversity*, 4 EVOLUTIONARY ECOLOGY RESEARCH 457, 462-63 (2002). *See also* GROOMBRIDGE & JENKINS, *supra* note 41, at 64-65 (noting that a major source of loss of biodiversity is introduction of species in areas outside their typical natural range, thereby creating change at both community and ecosystem levels).

[390] WILLIAMSON, *supra* note 388, at 144. Attempts to eradicate the plant have run up against the fact that an endangered flycatcher species has learned to nest in it. Erika S. Zavaleta et al., *Viewing Invasive Species Removal in a Whole-Ecosystem Context*, 16 TRENDS IN ECOLOGY AND EVOLUTION 454, 455 (2001).

[391] Daniel Simberloff & Betsy Von Holle, *Positive Interactions of*

introduced species survives but the parasites that affect it in its native territory do not.[392] Similarly, the increasing spread of disease by rapid means of travel around the world is a threat to local species that have never been exposed to such diseases.[393] Some observers argue that the globalization of so many species is reducing the diversity of ecological systems worldwide because so many of them are becoming occupied by similar species.[394] There are also suggestions that a warming climate may enhance the capability of species to invade new territories.[395]

But what makes a species "exotic"? Any attempt to define "exotic" species must address the issue of unassisted migration versus introduction by humans.[396] Is an animal or plant that

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*Nonindigenous Species: Invasional Meltdown?*, 1 BIOLOGICAL INVASIONS 21, 29 (1999).

[392] Mark E. Torchin et al., *Invading Species and Their Missing Parasites*, 421 NATURE 628 (2003) (finding that in a study of twenty-six species of various kinds of introduced animals, the number of parasites in the introduced populations was only about half of the number of parasite species found on the same animals in their home range). *See also* Charles E. Mitchell & Alison G. Power, *Release of Invasive Plants from Fungal and Viral Pathogens*, 421 NATURE 625 (2003) (finding that plants naturalized to the United States from Europe have fewer fungi and virus infections than they do in Europe).

[393] *See* Deborah J. Pain & Paul F. Donald, *Outside the Reserve: Pandemic Threats to Bird Biodiversity*, *in* CONSERVING BIRD DIVERSITY: GENERAL PRINCIPLES AND THEIR APPLICATION 157, 176-77 (Ken Norris & Deborah J. Pain eds., 2002). Recent examples of animal diseases spreading to humans have increased the concern about exotic species. *See, e.g.*, Chris Dye & Nigel Gay, *Modeling the SARS Epidemic*, 300 SCI. 1884 (2003).

[394] J. Baird Callicott et al., *Current Normative Concepts in Conservation*, 13 CONSERVATION BIOLOGY 22, 25 (1999). The ornithologist Alexander F. Skutch goes further. He argues that overpopulation—too many animal species and too many individual animals—is responsible for the gravest ills that affect the living world, including the prevalence of predation. What the natural world lacks, he says, is "moderation." ALEXANDER F. SKUTCH, A NATURALIST ON A TROPICAL FARM 381-82 (1980).

[395] *See, e.g.*, John J. Stachowicz et al., *Linking Climate Change and Biological Invasions: Ocean Warming Facilitates Nonindigenous Species Invasions*, 99 PROC. NAT'L ACAD. OF SCI. 15497 (2003); Jesse A. Logan et al., *Assessing the Impacts of Global Warming on Forest Pest Dynamics*, 1 FRONTIERS IN ECOLOGY AND THE ENV'T 130 (2003) (the increase in hot, dry weather in the Western United States has contributed to insect outbreaks in northern forests). Elevated carbon dioxide levels may also contribute to greater invasions by non-native plants. Jake F. Weltzin et al., *Biological Invasions in a Greenhouse World: Will Elevated $CO_2$ Fuel Plant Invasions?*, 1 FRONTIERS IN ECOLOGY AND THE ENV'T 146 (2003).

[396] The topic of biological invasions is comprehensively summarized in WILLIAMSON, *supra* note 388. *See also generally* J.A. Drake et al. eds., BIOLOGICAL INVASIONS: A GLOBAL PERSPECTIVE (1989).

expands its range on its own an "exotic" in its new territory? Without human intervention, the cattle egret expanded its original range—the African savanna—first to South America and by now to almost the entire United States.[397] Horses were native to the northern part of the western hemisphere until about 10,000 years ago, when they went extinct, perhaps from hunting by early humans. Horses were later reintroduced by humans about 500 years ago—apparently the same species but undoubtedly with significantly different genetic material. Are horses native or exotic?[398] From a historical perspective, some species (such as the European starling in North America) have been present for so long that "there is little point in regretting the history that has made them part of the ecosystems they now inhabit."[399] Finding agreement among biologists about the desirability of particular exotic species has been difficult.[400]

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[397] KENN KAUFMANN, BIRDS OF NORTH AMERICA 146 (2000). *See also* Daniel B. Botkin, *The Naturalness of Biological Invasions*, 61 WESTERN NORTH AM. NATURALIST 261, 262 (2001) (discussing transcontinental migration and establishment of the Cattle Egret beginning in the late nineteenth century, without human assistance).

[398] *See* Callicott et al., *supra* note 394, at 26. Purple loosestrife, commonly regarded as a harmful exotic, may actually be a native plant, and recent studies suggest that it has not been harmful to species diversity generally. Slobodkin, *supra* note 372, at 8. A decision of the District of Columbia Court of Appeals rejected FWS's refusal to list the mute swan as a migratory bird, pointing out that the Migratory Bird Treaty Act, 16 U.S.C. §§ 703-712 (2000), did not distinguish between native birds and those like the mute swan, which probably descended from birds introduced for ornamental purposes in the mid-nineteenth century. Hill v. Norton, 275 F.3d 98, 99 (D.C. Cir. 2001). On the other hand, the Seventh Circuit Court of Appeals held that the United States Forest Service was justified in excluding the shortleaf pines from a list of species native to the Shawnee National Forest because this species had been introduced to the project area in recent times. Glisson v. United States Forest Service, 138 F.3d 1181, 1183 (7th Cir. 1998).

[399] William Cronon, *Resisting Monoliths and Tabulae Rasae*, 10 ECOLOGICAL APPLICATIONS 473, 475 (2000). *Cf. also* Pierre Boursot, *Partitioning of Genetic Diversity in the House Mouse*, *in* MOLECULAR TOOLS FOR SCREENING BIODIVERSITY 431, 433 (Angela Karp et al. eds., 1998) (the house mouse originated in India and three subspecies now reflect wide geographic distribution). Many familiar North American plants, such as the dandelion and Queen Anne's lace, are also exotics. JASON VAN DRIESCHE & ROY VAN DRIESCHE, NATURE OUT OF PLACE: BIOLOGICAL INVASIONS IN THE GLOBAL AGE 93 (2002)

[400] There is no dispute among scientists that introduced species can often drive native species to extinction. David M. Lodge & Kristin Shrader-Frechette, *Nonindigenous Species: Ecological Explanation, Environmental Ethics, and Public Policy*, 17 CONSERVATION BIOLOGY 31, 34 (2003). But most biologists

Confusion also exists about those species that are non-native and those that are simply widespread generalists. Some kinds of organisms seem to be found almost everywhere, while others exist only under very specialized conditions.[401] Biologists often refer unflatteringly to the generalists—both plant and animal—as "weedy" species,[402] and sometimes assume that weedy species need no protection because they are natural survivors,[403] but weed is a term that has become more of an epithet than a scientific category.[404]

What are the characteristics of a weedy species? Some have the ability to adapt their behavior patterns to a wide variety of locations.[405] Weediness can protect diversity when a native

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think that there are no general rules for determining when a species will become invasive; the process is idiosyncratic and unpredictable. *See* discussion at notes 450-453 *infra*.

[401] Early ecologists made a sharp distinction between these two categories of organisms, but although a spectrum between general and specialized can be identified, the idea of two distinct categories is now thought to be a "gross oversimplification." McKinney, *supra* note 242, at 11.

[402] For example, in response to the argument that we should emphasize the protection of ecological processes rather than individual species, the famous biologist Michael Soulé responded scathingly that these processes "can be performed by weedy species." Michael E. Soulé, *Are Ecosystem Processes Enough?*, 6 WILD EARTH 59 (1996). Similarly, a survey of current conditions on coral reefs deplores the increasing predominance of "short-lived 'weedy' corals." Nancy Knowlton, *The Future of Coral Reefs*, 98 PROC. NAT'L ACAD. SCI. 5419 (2001). *See also* Lodge & Shrader-Frechette, *supra* note 400, at 32 (scientists should avoid making normative judgments under the banner of scientific credibility).

[403] Mace et al., *supra* note 241, at 1708 ("[G]eneralists such as small rodents and carnivores stand ready to invade globally . . . ."). Indeed, some botanists are concerned that some of the human-caused changes in ecological systems, such as large increases in the rate of nitrogen deposition, may result in dominance of the ecosystem by a few weedy plant species. David Tilman & Clarence Lehman, *Human-Caused Environmental Change: Impacts on Plant Diversity and Evolution*, 98 PROC. NAT'L ACAD. SCI. 5433, 5437-39 (2001). On the other hand, some studies suggest that disturbance does not promote generalists over specialists. Diego P. Vasquez & Daniel Simberloff, *Ecological Specialization and Susceptibility to Disturbance: Conjectures and Refutations*, 159 AM. NATURALIST 606, 619 (2002).

[404] WILLIAMSON, *supra* note 388, at 59 ("The definition of weed relates to human perception, and human perceptions vary."). After reviewing a good deal of biological literature on the subject, I have concluded that a weed can be defined as a form of life that someone wished he hadn't found where he found it. Aldo Leopold wrote an amusing commentary on the tendency of agriculturalists to call everything a weed, but he didn't publish it during his lifetime. *See* ALDO LEOPOLD, FOR THE HEALTH OF THE LAND 207-12 (Eric Freyfogle ed., 1999).

[405] For example, the Rock Dove, which originally nested on cliffs, adapted to

species is threatened by invasive exotic species or by environmental change. For example, in his extensive studies of the beautiful Hawaiian honeycreepers, Leonard Freed concluded that the relatively few species of honeycreeper that have survived in the form of healthy populations did so because of their "weedy" ability to adapt to a variety of ecological niches.[406]

Plants also can be considered weeds when they find an ecological niche in which the native plants are unable to compete successfully, as is true for the Melaleuca that has taken over much of the swamp edge niche in South Florida.[407] It is also worth noting that one of the most successful weedy species on earth is *homo sapiens*.[408]

Other weedy species have excellent dispersal abilities that enable them to spread rapidly and widely, like the house sparrow[409] and the starling.[410] An organism doesn't need to be big

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cliff-like city buildings and became known as our urban pigeon. MIKLOS D. F. UDVARDY, THE AUDUBON SOCIETY FIELD GUIDE TO NORTH AMERICAN BIRDS: WESTERN REGION 545-46 (1998).

[406] Freed, *supra* note 132, at 151-53. *See also* Angus Buckling et al., *Adaptation Limits Diversification of Experimental Bacterial Populations*, 302 SCI. 2107 (2003) ("[N]iche specialization may come with a cost of reduced potential to diversify.").

[407] WILLIAMSON, *supra* note 388, at 77. The Nature Conservancy maintains a website for information about invasive plants. THE NATURE CONSERVANCY, INVASIVES ON THE WEB, *at* http://tncweeds.ucdavis.edu (last updated Feb. 2004).

[408] POTTS, *supra* note 70, at 238. Another extremely weedy species is the common housecat. A study of midwestern farms found that the average farm had 5.6 free-ranging cats. Philip C. Mankin & Richard E. Warner, *Mammals of Illinois and the Midwest: Ecological and Conservation Issues for Human-Dominated Landscapes*, *in* CONSERVATION IN HIGHLY FRAGMENTED LANDSCAPES 135, 146 (Mark W. Schwartz ed., 1997). Free-ranging cats hunt small birds and other animals for recreation even if the cats are well-fed by humans. GUY R. MCPHERSON & STEPHEN DESTEFANO, APPLIED ECOLOGY AND NATURAL RESOURCE MANAGEMENT 21-22 (2003). When bird lovers clash with cat lovers, emotions can run high. Pamela Jo Hatley, Note, *Feral Cat Colonies in Florida: The Fur and Feathers are Flying*, 18 J. LAND USE & ENVTL. L. 441 (2003).

[409] WILLIAMSON, *supra* note 388, at 47-48, 50-52. Where habitat is changing rapidly due to human-caused development, good dispersers are at a particular advantage. Peter Kareiva & Uno Wennergren, *Connecting Landscape Patterns to Ecosystem and Population Processes*, 373 NATURE 299, 300 (1995).

[410] CHARLES ELTON, THE ECOLOGY OF INVASIONS BY ANIMALS AND PLANTS 24-26 (1958). In some cases, however, good dispersers have traded off competitive ability, and vice versa. David Tilman, *Community Diversity and Succession: The Roles of Competition, Dispersal, and Habitat Modification*, *in* BIODIVERSITY AND ECOSYSTEM FUNCTION 327, 339 (Ernst-Detlef Schulze & Harold A. Mooney eds., 1994).

to achieve such rapid dispersion.[411] Although few people would describe the Monarch butterfly as weedy, its wide range and prolific numbers would seem to meet most definitions of a weed.[412]

A species can be treated as a weed simply because it is too good at competing with its congenerics, such as the African bees that have expanded their range throughout the Americas because they have been able to out compete honeybees—which are themselves exotics.[413] Other species reproduce so rapidly that they crowd out most competitors of all types, like the rabbits did in Australia.[414]

Will environmental change endanger some of the species that we now consider weeds? The passenger pigeon and the bison were, after all, once among the most visible species in America; the one is gone and the other narrowly escaped extinction.[415] Populations of the common house sparrow are now declining rapidly in Europe.[416] Ecologists increasingly question the common

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[411] Large animals may often seem to dominate smaller animals, but large size requires more energy, and in times of shortage smaller species may have a distinct advantage. ROSENZWEIG, *supra* note 182, at 155.

[412] *See generally* Grace, *supra* note 101.

[413] WILLIAMSON, *supra* note 388, at 156-60. Actually, although most people assume honeybees are a native species, they were not native to the Western hemisphere, but were introduced around 1600. RENÉ DUBOS, THE WOOING OF EARTH 86 (1980). The so-called African honeybee came from Southern Europe and North Africa, and was better suited to the climate of the southern United States than the bees from Northern Europe that were imported in colonial days. MARK WINSTON, KILLER BEES: THE AFRICANIZED HONEY BEE IN THE AMERICAS 17-18 (1992). Molecular analysis now enables phylogeneticists to trace the origin of various honeybee colonies. AVISE, *supra* note 125, at 197-98. There are some 4000 species of native bees remaining in the United States. Stein et al., *supra* note 86, at 76.

[414] CHRIS BRIGHT, LIFE OUT OF BOUNDS: BIOINVASION IN A BORDERLESS WORLD 140-41 (1998). In general, increasing the number of propagates increases the likelihood that a species will become established. WILLIAMSON, *supra* note 388, at 45. Conversely, in highly competitive or rapidly changing environments, a species without a high reproductive rate may be more likely to become extinct. *See* Freed, *supra* note 132, at 155-56.

[415] Master et al., *supra* note 199, at 93-94, 208. The total population of passenger pigeons at their peak has been estimated to be about three billion birds, constituting between twenty-five to forty percent of the total bird population of the United States. A. W. SCHORGER, THE PASSENGER PIGEON: ITS NATURAL HISTORY AND EXTINCTION 205 (1955).

[416] Populations of the house sparrow have declined throughout Western Europe in recent decades. David G. Hole et al., *Widespread Local House-Sparrow Extinctions: Agricultural Intensification Is Blamed for the Plummeting*

assumption that all weedy species are undesirable and require no protection.[417]

Insofar as global biodiversity is concerned, the overall impact of exotic species is not easy to determine. Although exotic species may occasionally contribute to global losses in biodiversity by out-competing certain native species to the point of extinction, exotic species often contribute heavily to local biodiversity.[418] Hawaii once had 800 plants; now it has 1600, while only about thirty went extinct.[419] Thus the state's biodiversity has increased, though most biologists consider the changes to have been tragic.[420] Similarly, in a study of 125 North American watersheds, University of New Mexico ecologist James Brown found that an increase in the number of colonizing exotic species usually increased local diversity of species.[421]

An increasing number of biologists and resource managers argue that the fight against exotics has been oversold.[422] Most

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*Populations of These Birds*, 418 NATURE 931 (2002).

[417] *See, e.g.*, ANDREW P. DOBSON, CONSERVATION AND BIODIVERSITY 224-25 (1996). In the 1960s, ecologists thought it was useful to classify species of plants and animals into two categories, the weedy species that thrived in unstable environments and the climax species that dominated stable environments (*r*- and *K*-selection), but later research showed that this was a "caricature of reality." David Reznick et al., r- *and* K-*selection Revisited: The Role of Population Regulation in Life-History Evolution*, 83 ECOLOGY 1509 (2002).

[418] BROWN, *supra* note 108, at 217-24.

[419] James H. Brown, *Regulation of Diversity: Colonization, Extinction, and Carrying Capacity of Species* (paper delivered at the Conference on Integration Across Ecological Scales, Texas A & M University, Feb. 25, 2000). The 230-240 existing native land bird species of Hawaii and nearby islands are the remnants of up to 1500 species that existed before human occupation of the islands. John Cornutt & Stuart Pimm, *How Many Bird Species in Hawaii and the Central Pacific before First Contact*, 22 STUDIES IN AVIAN BIOLOGY 15 (2001).

[420] For an example of the problems involved, see Kenneth Brower, *The Pig War*, *in* A WORLD BETWEEN THE WAVES 71 (Frank Stewart ed., 1992). *See generally* CONSERVATION BIOLOGY IN HAWAII (Charles P. Stone & Danielle B. Stone eds., 1989); Lloyd L. Loope & Dieter Mueller-Dombois, *Characteristics of Invaded Islands, with Special Reference to Hawaii*, *in* BIOLOGICAL INVASIONS: A GLOBAL PERSPECTIVE 257, 260-63 (J. A. Drake et al. eds., 1989).

[421] James H. Brown, *supra* note 419. *See* Michael L. McKinney, *Do Human Activities Raise Species Richness? Contrasting Patterns in United States Plants and Fishes*, 11 GLOBAL ECOLOGY & BIOGEOGRAPHY 343 (2002) (finding that as human population grows, the trend is toward more plants, but fewer fish species).

[422] *See* SLOBODKIN, *supra* note 11, at 144-53. *See also* Matthew K. Chew & Manfred D. Laubichler, *Natural Enemies–Metaphor or Misconception*, 301 SCI. 52 (2003); Botkin, *supra* note 397, at 261-62. For media coverage, see Andrew

invading species never become established, and of those that do only a small percentage cause significant problems.[423] Brown argues that "cosmopolitization" of the earth's biota is inevitable and may be desirable because exotic species tend to increase local diversity, even while potentially decreasing global diversity.[424] Because local diversity promotes ecological stability, the advantages may outweigh the disadvantages. Some biologists advise that exotic species that "offer the least threat to native biological diversity and exert the least dramatic change on ecosystem processes" should be tolerated,[425] a test that the starling would certainly flunk.[426] Some exotic species that are widely seen by humans to be pests may actually create economic benefits. For example, it has been estimated that *Solenopsos invicta*, the notorious fire ant, may actually provide economic benefits to humans by controlling other insects that damage agricultural crops,[427] although it has decimated the populations of many native ants.[428]

Some invasive species may not threaten diversity because

C. Revkin & Carol Kaesuk Yoon, *As Alien Invaders Proliferate, Conservationists Change their Focus*, N.Y. TIMES, Aug. 20, 2002, at F10; Mark Sagoff, *Why Exotic Species Are Not as Bad as We Fear*, CHRONICLE OF HIGHER EDUCATION, June 23, 2000, at B7, and responsive letters, *id*., Aug. 4, 2000, at B10-11.

423 WILLIAMSON, *supra* note 388, at 33 ("A useful rule of thumb is the tens rule, that 10% of . . . invasive species living outside of captivity in any sense, become established, and 10% of those established become pests."). *See also* Gregory M. Ruiz et al., *Non-Indigenous Species as Stressors in Estuarine and Marine Communities: Assessing Invasion Impacts and Interactions*, 44 LIMNOLOGY AND OCEANOGRAPHY 950, 963 (1999) (stating that of the non-indigenous species in Chesapeake Bay, there is quantitative data on the impact of only about six percent, and much of it is inconclusive, but there is reason to believe that up to twenty percent of the species may have some significant impact).

424 BROWN, *supra* note 108, at 217-24.

425 John J. Ewel, *Ecosystem Processes and the New Conservation Theory*, *in* THE ECOLOGICAL BASIS OF CONSERVATION: HETEROGENEITY, ECOSYSTEMS, AND BIODIVERSITY 252, 259 (Steward Pickett et al. eds., 1997). *See generally* Lodge & Shrader-Frechette, *supra* note 400.

426 Michael L. Rosenzweig, *Ecology Should Take Credit for Its Accomplishments: A Reply*, 4 EVOLUTIONARY ECOLOGY RESEARCH 465 (2002) (calling the starling an "avian cockroach").

427 J. Howard Frank et al., *Immigration and Introduction of Insects*, *in* STRANGERS IN PARADISE: IMPACT AND MANAGEMENT OF NONINDIGENOUS SPECIES IN FLORIDA 75, 92 (Daniel Simberloff et al. eds., 1997).

428 Mooney & Cleland, *supra* note 387, at 5449.

they apparently fit into partially empty niches.[429] For example, although the purple loosestrife is usually considered highly invasive, a number of studies suggest that there is little evidence that loosestrife has caused the decline of any other species.[430] Similarly, although the eucalyptus is not native to California, a comparison of oak and eucalyptus forests in California found no difference in species richness.[431] Even the zebra mussel[432] apparently thrives because it fits into a niche that no native mussel had exploited; no native adult mussels have byssal threads that allow attachment to rocks or plants in the productive littoral zone; in addition, the active pumping of the zebra mussel is better suited to exploit the resources (e.g., insect larvae) of calmer waters than are the passive filtering systems of native species.[433] Although the zebra mussel is sometimes feared as a threat to native mussel species,[434] conservation biologists believe the primary threats to native mussels come from pollution, siltation, and loss of flowing river habitat in the southeastern states where they have predominated.[435]

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[429] L. B. Slobodkin, *Limits to Biodiversity (Species Packing)*, 3 ENCYCLOPEDIA OF BIODIVERSITY 729, 735 (Simon A. Levin ed., 2001); Botkin, *supra* note 397.

[430] Mark G. Anderson, *Interactions Between Lythrum salicaria and Native Organisms: A Critical Review*, 19 ENVTL. MANAGEMENT 225 (1995); Heather A. Hager & Karen D. McCoy, *The Implications of Accepting Untested Hypotheses: A Review of the Effects of Purple Loosestrife (Lythrum Salicaria) in North America*, 7 BIODIVERSITY AND CONSERVATION 1069 (1998); Michael A. Treberg & Brian C. Husband, *Relationship Between the Abundance of Lythrum salicariaI (Purple Loosestrife) and Plant Species Richness along the Bar River, Canada*, 19 WETLANDS No. 1, at 118 (1999). Nevertheless, weed specialists continue to recommend eradication of purple loosestrife. Barbra H. Mullin, *The Biology and Management of Purple Loosestrife (Lythrum salicaria)*, 12 WEED TECH. 397 (1998).

[431] Dov V. Sax, *Equal Diversity in Disparate Species Assemblages: A Comparison of Native and Exotic Woodlands in California*, 11 GLOBAL ECOLOGY & BIOGEOGRAPHY 49, 53-56 (2002).

[432] For a bibliography of material on the zebra mussel, see NAT'L INVASIVE SPECIES COUNCIL, ZEBRA MUSSEL PROFILE, *at http://www.invasivespecies.gov/profiles/zebramussel.shtml* (last visited Feb. 4, 2004).

[433] Daniel Simberloff, *Community and Ecosystem Impacts of Single-Species Extinctions*, *in* THE IMPORTANCE OF SPECIES: PERSPECTIVES ON EXPENDABILITY AND TRIAGE 221, 223 (Peter Kareiva & Simon A. Levin eds., 2003).

[434] BRIGHT, *supra* note 414, at 96-98, 181-82.

[435] Freshwater mussels as a group are ranked among the most endangered in the United States. Master et al., *supra* note 199, at 93, 108. Because native mussel species are concentrated in the Southeastern states they are subject to a high degree of pollution from agricultural runoff. *See* Stephen J. Chaplin et al.,

In addition, individual organisms that appear to be outside their normal range, and thus would be classified as exotic, may be responding to environmental factors such as climate change that are forcing them out of traditional locations.[436] One study estimates that climate change is forcing species to relocate at a rate ten times faster than occurred during the climate change at the end of the last ice age.[437] Birds and fish, in particular, have a high degree of mobility and frequently expand or contract their ranges in response to environmental changes.[438] In some cases, so-called exotic species of one area may be surplus individuals today, but might become needed to recolonize a source area at some future time.[439] Therefore, colonies of what appear to be exotic organisms may play an important role in the preservation of their species in

*The Geography of Imperilment: Targeting Conservation toward Critical Biodiversity Areas*, *in* PRECIOUS HERITAGE: THE STATUS OF BIODIVERSITY IN THE UNITED STATES 159, 180-82 (Bruce A. Stein et al. eds., 2000). Habitat loss, pollution, and siltation are ranked ahead of invasive species as threats to American mussels generally. David S. Wilcove, *Leading Threats to Biodiversity: What's Imperiling U.S. Species*, *in* PRECIOUS HERITAGE: THE STATUS OF BIODIVERSITY IN THE UNITED STATES 239, 242-49 (Bruce A. Stein et al. eds., 2000).

[436] *See, e.g.*, Lisa Crozier, *Winter Warming Facilitates Range Expansion: Cold Tolerance of the Butterfly Atalopedes campestris*, 135 OECOLOGIA 648, 653-55 (2003); Lisa Crozier, *Warmer Winters Drive Butterfly Range Expansion by Increasing Survivorship*, 85 ECOLOGY 231 (2004) (noting that expansion of range of the sachem skipper butterfly from California into Oregon and Washington has accompanied warming trend in winter temperatures). *But see* Jeffrey S. Dukes, *Will the Increasing Atmospheric $CO_2$ Concentration Affect the Success of Invasive Species?*, *in* INVASIVE SPECIES IN A CHANGING WORLD 95, 106 (Harold A. Mooney & Richard J. Hobbs eds., 2000) ("Invasiveness and $CO_2$ responsiveness are not clearly linked.").

[437] David W. Macdonald & Dominic D. P. Johnson, *Dispersal in Theory and Practice: Consequences for Conservation Biology*, *in* DISPERSAL 358, 366 (Jean Clobert et al. eds., 2001). *See also* Mark B. Bush et al., *48,000 Years of Climate Change in a Biodiversity Hot Spot*, 203 SCI. 827, 829 (2004) (although current rate of climate change is more rapid than the warming at the end of the ice age, the narrowness of elevation belts on the slopes of the Andes Mountains may make adaptation by upward migration possible there). Even such immobile species as staghorn and elkhorn corals may be migrating northward. Johanna Polsenberg, *Coral May be Moving North*, 1 FRONTIERS IN ECOLOGY AND THE ENV'T 512 (2003).

[438] *See, e.g.*, WEIDENSAUL, *supra* note 295, at 48-54, 90, 201, 224-38, 362 (1999) (giving many examples); Bengt-Owe Jansson & Ann-Mari Jansson, *The Baltic Sea: Reversibly Unstable or Irreversibly Stable?*, *in* RESILIENCE AND THE BEHAVIOR OF LARGE-SCALE SYSTEMS 71, 79-81 (Lance H. Gunderson & Lowell Pritchard Jr. eds., 2002).

[439] BROWN, *supra* note 108, at 217-24.

case of future disturbance of the original source habitat.[440]

In other cases, invasive species may increase biodiversity by preying on the predators of endangered species. For example, on New Zealand's Stewart Island, invasive feral cats prey on an endangered parrot, but the the mainstay of the of the cats' diet is rats, which attack the parrots nests, so elimination of the cats could harm the parrot more than it would help it.[441] Relatively rapid evolution has been discovered in both invading species and in native species that are responding to an invasion.[442] Any concern about harms caused by exotic species must be balanced by an evaluation of the potential harm that that might result from controlling the species by the release of its natural enemies.[443]

The foregoing arguments suggest caution in defining and dealing with exotic species. On the other hand, some highly regarded biologists, such as the University of Tennessee at Knoxville's Daniel Simberloff, not only advocate prohibiting new introductions of species but say that, if introductions occur, they should be met by a "quick and dirty response, mechanical or chemical or both."[444] Because introduced species have rapid expansion and dispersal capabilities, Simberloff argues, they are "one target of resource management at which it is often better to shoot first and ask questions later."[445] Some Hawaiian biologists, who have long and painful experience with exotic species, share similar views.[446]

Does the issue of invasive species deserve higher priority?

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[440] *See* Pickett & Rogers, *supra* note 211, at 112. The effect of dispersal on the preservation of diversity is more fully discussed at notes 514-554 *infra*.

[441] Erika S. Zavaleta et al., *supra* note 390. The elimination of goats and pigs from an island in the Northern Marianas "explosively released a previously undetected exotic vine" that literally covered the island. *Id*. at 458.

[442] Mooney & Cleland, *supra* note 387, at 5447.

[443] VAN DRIESCHE & VAN DRIESCHE, *supra* note 399, at 237-43 (describing attempts to use imported beetles to control purple loosestrife); PIMM, *supra* note 260, at 212 (describing havoc caused by snail imported to control another exotic snail in Hawaii).

[444] Daniel Simberloff, *How Much Information on Population Biology Is Needed to Manage Introduced Species?*, 17 CONSERVATION BIOLOGY 83, 89 (2003).

[445] *Id*. at 88.

[446] *See, e.g.*, Lloyd L. Loope et al., *Newly Emergent and Future Threats of Alien Species to Pacific Birds and Ecosystems*, 22 STUDIES IN AVIAN BIOLOGY 291, 304 (2002) (arguing that early detection and treatment of invaders before explosive spread occurs can prevent problems).

Should we be paying as much attention to invasions as we do to extinctions?[447] Via an executive order, President Clinton created a National Invasive Species Council to recommend a coordinated approach for dealing with invasive species.[448] The Council proposed the creation of a new National Center for Biological Invasions, which has now begun work.[449]

The Council's task would be easier if biologists could identify either the attributes of species that are likely to become invasive,[450] or the attributes of those habitats that are most likely to become invaded.[451] A National Research Council committee recognized

[447] Marjorie J. Wonham, *Ecological Gambling: Expendable Extinctions Versus Acceptable Invasions*, *in* THE IMPORTANCE OF SPECIES: PERSPECTIVES ON EXPENDABILITY AND TRIAGE 179, 199-203 (Peter Kareiva & Simon A. Levin eds., 2003).

[448] Exec. Order No. 13,112, 3 C.F.R. 159 (2000). The Order proposes to integrate the administration of numerous federal statutes including the National Environmental Policy Act of 1969, 42 U.S.C. §§ 4321-4370d (2000); the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990, 16 U.S.C. §§ 4701 (2000); the Lacey Act, 18 U.S.C. §§ 42 (2000); the Federal Plant Pest Act, 7 U.S.C. §§ 150aa (2000); the Federal Noxious Weed Act of 1974, 7 U.S.C. §§ 2801 (2000), the Endangered Species Act of 1973, 16 U.S.C. §§ 1531-1544 (2000), and other pertinent statutes, to prevent the introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts that invasive species cause. Exec. Order No. 13,112, 3 C.F.R. 159. At the international level, the Conference of Parties to the Convention on Biological Diversity has also suggested guidelines for managing the international spread of alien species. Saskia Young, *Developments in Biodiversity 2002*, 2002 COLORADO J. INT'L. ENVTL. L. AND POL'Y 17, 20-21 (2002).

[449] The Council also maintains a website. NAT'L INVASIVE SPECIES COUNCIL, WELCOME TO INVASIVESPECIES.GOV!, *at http://www.invasivespecies.gov* (last visited March 6, 2004). The Council opposes only those invasive species that are harmful or potentially harmful. Lodge & Shrader-Frechette, *supra* note 400, at 35. On the Council's origins, see Don C. Schmitz & Daniel Simberloff, *Needed: A National Center for Biological Invasions*, ISSUES IN SCI. & TECH. ONLINE, *at* http://*www.nap.edu/issues/17.4/schmitz.htm* (last visited Feb. 4, 2004). *See also* VAN DRIESCHE & VAN DRIESCHE, *supra* note 399, at 150-51.

[450] Few people think that this task is easy. *See* Bond, *supra* note 218; Ann K. Sakai et al., *The Population Biology of Invasive Species*, 32 ANN. REV. OF ECOLOGY AND SYSTEMATICS 305, 323-25 (2001). *But see* Marcel Rejmanek & David M. Richardson, *What Attributes Make Some Plant Species More Invasive?*, 77 ECOLOGY 1655, 1659 (1996) (identifying characteristics of invasive conifers). *See also* Michael L. Rosenzweig, *Loss of Speciation Rate Will Impoverish Future Diversity*, 98 PROC. NAT'L ACAD. SCI. 5404, 5408-09 (2001); Mark W. Schwartz & Phillip J. van Mantgem, *The Value of Small Preserves in Chronically Fragmented Landscapes*, *in* CONSERVATION IN HIGHLY FRAGMENTED LANDSCAPES 379, 389 (Mark W. Schwartz ed., 1997).

[451] *See, e.g.*, Graeme S. Cumming, *Habitat Shape, Species Invasions, and*

the existence of the problem but could offer few suggestions for predicting which plants and plant pests would become invasive:

> From the case histories of individual invasions, it is apparent that the transition in each case has been propelled by a unique and accidental chain of events in which community dynamics and the resources of the environment interact with the biological characteristics of an established species in a way that fosters its proliferation. At each turn, these events enable other traits to reinforce the growth and spread of the population. The nexus of the community, its environment, and the size of the population is crucial, but so little is known quantitatively about many of these interactions that using them in a predictive manner remains difficult.[452]

Attempts to predict the type of habitats most likely to become adversely affected by invaders are at a very early stage.[453] All of

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*Reserve Design: Insights from Simple Models*, 6 CONSERVATION ECOLOGY, No. 1, at 3 (2002).

[452] NAT'L RESEARCH COUNCIL, PREDICTING INVASIONS OF NONINDIGENOUS PLANTS AND PLANT PESTS 78-79 (2002), *available at* http://www.nap.edu/openbook/0309082641/html/R1.html (last visited Feb. 5, 2004). *See also* Slobodkin, *supra* note 372, at 8 (it cannot be clearly predicted which invasive species will out-compete native species). Studies of potentially invasive characteristics are continuing. *See, e.g.*, Sakai et al., *supra* note 450 (rapidly evolving species may be most likely to spread). For birds, existing range size in their native area may correlate with invasive capability. Tim M. Blackburn & Richard P. Duncan, *Determinants of Establishment Success in Introduced Birds*, 414 NATURE 195, 196 (2001), stating:

> Our results show that for birds the outcome of introductions is not predicted by general features of locations related to biotic resistance (such as latitude), and that the success of a species cannot be predicted from that of its relatives. Instead, the importance of phylogenetically labile species-specific factors, such as geographical range size, and event-level effects related to environmental suitability, such as the match between latitudes of origin and introduction, suggest that success depends on the particular combination of species and location.

*See also* Michael P. Moulton et al., *Patterns of Success Among Introduced Birds in the Hawaiian Islands*, 22 STUDIES IN AVIAN BIOLOGY 31, 35 (2001).

[453] A review of over a hundred studies of invasive plants was critical of the failure of most studies to examine the ecological processes that facilitated the invasions. Jonathan M. Levine et al., *Mechanisms Underlying the Impacts of Exotic Plant Invasions*, 270 PROC. OF THE ROYAL SOC. OF LONDON B 775 (2003). Some studies suggest that areas of high native biodiversity are also most susceptible to invasion by exotics because they are not areas undergoing severe stresses. J. M. Levine et al., *Neighbourhood Scale Effects of Species Diversity on Biological Invasions and Their Relationship to Community Patterns*, *in* BIODIVERSITY AND ECOSYSTEM FUNCTIONING: SYNTHESIS AND PERSPECTIVES 114, 118, 124 (Michel Loreau et al. eds., 2002); Scott J. Meiners et al., *Beyond Biodiversity: Individualistic Controls of Invasion in a Self-Assembled*

this controversy suggests that the issue of exotic species deserves serious attention, but that it is not the simple "bad guy" versus "good guy" scenario that some may assume.

**PUZZLE #8:**
**WHAT CRITERIA SHOULD BE USED TO DECIDE WHETHER A SPECIES OF PLANT OR ANIMAL HAS AN ADVERSE EFFECT ON BIODIVERSITY BECAUSE IT ARRIVED AT ITS PRESENT LOCATION BY THE WRONG METHOD OR AT THE WRONG TIME? WHAT SHOULD "WRONG" MEAN IN THIS CONTEXT?**

### 2. *PURE SPECIES VS. HYBRIDS*

Species with high hybridization potential are a special category. In general, a plant or animal will reproduce sexually only with another individual of the same species.[454] In practice, however, some species are sufficiently similar that crosses between them will occur if the species are brought together in the wild,[455] and the use of molecular genetic markers has made it possible to detect hybridization that might previously have gone unnoticed.[456]

Introduction of a potential hybridizing species may destroy the unique genetic characteristics of an existing population. The

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*Community*, 7 ECOLOGY LETTERS 121 (2004) (finding that, in a study of plots of abandoned agricultural land in New Jersey, plots with higher species richness had a greater risk of invasion by both native and exotic species). On the other hand, Stuart L. Pimm argues that species richness increases the likelihood of extinctions caused by future invasions because secondary extinctions propagate more widely in complex communities. Stuart L. Pimm, *Biodiversity and the Balance of Nature*, *in* BIODIVERSITY AND ECOSYSTEM FUNCTION 347, 357 (Ernst-Detlev Schulze & H. A. Mooney eds., 1994). One significant point the NRC committee made is that special attention ought to be paid to the increasing importation of plants for erosion control in land reclamation or restoration. As they put it, "[n]onindigenous species that can colonize a bare surface rapidly and remain persistent without maintenance might be deemed advantageous in land reclamation, but they have the potential to become invasive." NAT'L RESEARCH COUNCIL, *supra* note 452, at 31.

[454] NEW PENGUIN DICTIONARY OF BIOLOGY, *supra* note 18, at 524-25.

[455] Sometimes a species will interbreed with another species in some part of their common range but not in others. Should these hybrids be considered a separate species? PERLMAN & ADELSON, *supra* note 13, at 121.

[456] Fred W. Allendorf et al., *The Problems with Hybrids: Setting Conservation Guidelines*, 16 TRENDS IN ECOLOGY AND EVOLUTION 613, 614 (2001).

large-scale destruction of much of the old growth forest in the Pacific Northwest has allowed the barred owl to expand its range, and there is evidence that the barred owl is hybridizing with the endangered northern spotted owl.[457] Such hybridization can also occur when a species adjusts well to human-created habitats and expands its range to include more of those habitats, as in the case of the Mallard duck.[458] In some cases, such hybridization may even threaten a species with "genetic extinction."[459]

On the other hand, in highly inbred populations, hybridization may enhance the fitness of the species.[460] FWS has tried to improve the genetic characteristics of the endangered Florida panther by importing cougars from other regions to breed with the panthers.[461] Similar issues have arisen in trying to protect rare wolves.[462] FWS has been unable to develop any consistent policy on how to deal with this issue,[463] and the differing attitudes of phylogeneticists and taxonomists toward hybrids has made it difficult to reach a consensus.[464]

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[457] Lande, *supra* note 98, at 9-10. For other examples, see WILLIAMSON, *supra* note 388, at 164-68.

[458] Daniel Simberloff, *The Biology of Invasions*, *in* STRANGERS IN PARADISE: IMPACT AND MANAGEMENT OF NONINDIGENOUS SPECIES IN FLORIDA 3, 11-12 (Daniel Simberloff et al. eds., 1997) (stating that mallard expanded range and bred with endemic Florida mottled duck).

[459] Daniel Simberloff, *Nonindigenous Species: A Global Threat to Biodiversity and Stability*, *in* NATURE AND HUMAN SOCIETY: THE QUEST FOR A SUSTAINABLE WORLD 325, 328 (Peter H. Raven ed., 1997) (the New Zealand gray duck and the Hawaiian duck may become genetically extinct because of hybridization with introduced mallards). *See also* Dana E. Weigel et al., *Introgressive Hybridization between Native Cutthroat Trout and Introduced Rainbow Trout*, 13 ECOLOGICAL APPLICATIONS 38 (2003); Seth P. D. Riley et al., *Hybridization Between a Rare, Native Tiger Salamander (*Ambystoma Californiense*) and its introduced Congener*, 13 ECOLOGICAL APPLICATIONS 1263 (2003) (describing native species losing its genetic characteristics as a result of hybridization with introduced closely-related species).

[460] MAYR, *supra* note 273, at 171. *See, e.g.*, Dieter Ebert et al., *A Selective Advantage to Immigrant Genes in a* Daphnia *Metapopulation*, 295 SCI. 485 (2002).

[461] Stacy A. Barker, *Comment: The Use of the South Florida Multi-Species Recovery Plan to Restore Threatened and Endangered Species*, 9 DICK. J. ENVTL. L. & POL'Y 507, 525-27 (2001).

[462] *See* Elizabeth Cowan Brown, *The "Wholly Separate" Truth: Did the Yellowstone Wolf Introduction Violate Section 10(J) of the Endangered Species Act?*, 27 B.C. ENVTL. AFF. L. REV. 425, 426-29 (2000).

[463] Allendorf et al., *supra* note 456, at 615.

[464] AVISE, *supra* note 125, at 296-97. It is in these situations when conservation biologists often see a need to manipulate genetic diversity.

Problems have also arisen when closely related species of large carnivores, some of which are now rare, have hybridized as they expanded their range.[465] To the extent that this causes the hybrid to become less fit than either parent in either parental environment,[466] it is sometimes referred to as "outbreeding depression."[467] This problem is also significant in regard to rare plants; for example, analysis of the DNA of the last remaining population of the Catalina Island mountain mahogany has found that about half of the few remaining trees are hybrids carrying the genetic material of another, more widespread species.[468]

Other biologists point out, however, that hybridization is common in all major plant groups; for example, genetic research has shown that the common cattail is a hybrid between native and exotic species.[469] Hybrid plants often serve as refuges for rare species of insects[470] and fungi[471] (an attribute many gardeners have observed with dismay).[472] Many studies are now beginning to show that hybridization can serve as the basis for new species.[473]

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Holsinger & Vitt, *supra* note 84, at 202.

[465] Philip W. Hedrick, *Applications of Population Genetics and Molecular Techniques to Conservation Biology*, *in* GENETICS, DEMOGRAPHY AND VIABILITY OF FRAGMENTED POPULATIONS 113, 122-24 (Andrew G. Young & Geoffrey M. Clarke eds., 2000) (study of genetic variation among three populations of rare Mexican gray wolves found sufficient similarity to treat them as identical).

[466] WILSON, *supra* note 213, at 117 (arguing that the typical hybrid is not able to compete successfully with either parent).

[467] Michelle R. Dudash & Charles B. Fenster, *Inbreeding and Outbreeding Depression in Fragmented Populations*, *in* GENETICS, DEMOGRAPHY AND VIABILITY OF FRAGMENTED POPULATIONS 45-49 (Andrew G. Young & Geoffrey M. Clarke eds., 2000). However, not all hybridization adversely affects fitness. GRANT, *supra* note 63 at 420-21 (finch hybrids lost no fitness).

[468] Holsinger et al., *supra* note 98, at 28-29.

[469] NAT'L RESEARCH COUNCIL, *supra* note 452, at 91. *See also* ALEC L. PANCHEN, CLASSIFICATION, EVOLUTION AND THE NATURE OF BIOLOGY 58-59 (1992) (discussing hybridization and its implications for phylogeny reconstruction); Bisby et al., *supra* note 94, at 59-60 (noting widespread hybridism and its implications).

[470] Thomas G. Whitham et al., *Conservation of Hybrid Plants*, 254 SCI. 779, 779-80 (1991).

[471] Thomas G. Whitham et al., *Plant Hybrid Zones Affect Biodiversity: Tools for a Genetic-Based Understanding of Community Structure*, 80 ECOLOGY 416, 417-18 (1999).

[472] The "hybrid tea rose" is notoriously susceptible to insect pests and fungi. STEPHEN SCANNIELLO, A YEAR OF ROSES 132-33 (1997).

[473] ENDLESS FORMS: SPECIES AND SPECIATION 327-24 (Daniel J. Howard & Stewart H. Berlocher eds., 1998) (describing numerous such studies). *See also* Loren H. Rieseberg et al., *Major Ecological Transitions in Wild Sunflowers*

And don't new hybrids add to global species richness?[474]

Traditionally, it has been thought that most hybrids are sterile and unable to reproduce, like the mule, so they would not present a long-range problem,[475] but a very interesting recent study suggests that many Caribbean corals are actually sterile hybrids that are expanding their range. "As many as 105 coral species from thirty-six genera and eleven families reproduce in yearly, synchronous mass-spawning events, thereby providing overwhelming opportunities for hybridization among congenerics."[476]

Although many of the hybrid corals are sterile and unable to reproduce sexually, they "can propagate clonally by fragmentation, allowing for long-lived, potentially immortal genotypes. These 'immortal mules' may accumulate over time, providing the opportunity for rare backcrosses, and for the ecological persistence of a diverse suite of *Acropora* morphotypes that is greater than the number of species on the reefs."[477]

Coral diversity appears to be enhanced by these long-lived asexual hybrids, but they have little potential to evolve,[478] which again raises the issue of the extent to which evolutionary potential should be an important component of any definition of biodiversity.[479] These complex issues with regard to hybridization present yet another profound puzzle in defining biodiversity.

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*Facilitated by Hybridization*, 301 SCI. 1211, 1211 (2003) (noting that plants adapt to environmental change by hybridization).

474 *See* discussion of "alpha" diversity, *supra* note 41 and accompanying text.

475 OXFORD DICTIONARY OF BIOLOGY, *supra* note 18, at 300 ("Hybrids between different animal species are usually sterile, as is the mule (a cross between a horse and a donkey).").

476 Vollmer & Palumbi, *supra* note 85, at 2023 (citations omitted). *See also* Knowlton & Weigt, *supra* note 88, at 202-03.

477 Vollmer & Palumbi, *supra* note 85, at 2025 (citations omitted).

478 *Id*.

479 *See* discussion at notes 245-48 *supra*.

### PUZZLE #9:
### WHAT CRITERIA SHOULD DECIDE WHETHER A HYBRID SPECIES HAS A POSITIVE OR ADVERSE EFFECT ON BIODIVERSITY? WHEN SHOULD THE POTENTIAL TO CREATE NEW HYBRID SPECIES BE CONSIDERED AN ADDITION OR THREAT TO BIODIVERSITY?

## C. *Present or Future Diversity?*

What do we do if we are forced to make a trade-off between maintaining present biodiversity and creating conditions that we think will foster biodiversity in the future? This issue arises in a number of contexts, including the following: (1) Do we need to assist those species that have difficulty reacting to environmental change? (2) Should we foster or discourage natural speciation? (3) Should we actively create biodiversity through captive breeding and biotechnology? (4) Are there situations in which we need to concede that loss of local diversity is a necessary adaptive strategy? These questions will be addressed in order.

### 1. *Anticipating environmental change*

Over the last few decades, science has given us new tools to chart the distribution of species over space and time at far larger scales than were available earlier, and we now know that many species are reacting to a warming climate by gradually moving away from lower altitudes or toward the poles.[480] As one researcher has noted, "[e]nvironmental change is now occurring on a global scale due to human activities, and many species will have to adapt to this change or experience an ever-increasing chance of extinction."[481]

We now know that many species exist as metapopulations scattered about in heterogeneous landscapes—landscapes that are not only highly complex at any given point in time, but are continually changing in highly complex ways.[482] DNA analysis, field tracking technologies, computer modeling, and other scientific and technological advances are beginning to make it possible to understand how species in metapopulations live and

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[480] *See* discussion at notes 615-628 *infra*.
[481] Templeton, *supra* note 82, at 59.
[482] *See, e.g.*, Saccheri, *supra* note 58 (discussing metapopulations of butterflies).

die. Even with these tools, though, can we devise resource management methods that are designed to protect and enhance the future biodiversity of species in metapopulations?[483]

For a species to propogate, individual members of a species must allocate energy resources among two key functions: survival—including the need for appropriate habitat—and reproduction.[484] Species evolve strategies to adapt these functions to changing environmental conditions, and most existing species have survived ice ages, sea level changes, and tectonic plate movements, not to mention innumerable disturbances from storms, volcanoes, and other natural phenomena.[485] However, the rapid growth of human populations and technology is leading scientists to believe that humans are now causing environmental change at a rate far faster than has occurred at any time in the past.[486] Species' needs for new habitat—what biologists call "dispersal"—may grow at a rate that exceeds any past adaptive experience.[487] Should humans help maintain biodiversity by reinforcing and enriching the abilities of other species to adapt to these changes?

Biologists today recognize that environmental change is a natural feature of the history of the world,[488] and that some kinds of change are necessary in order to retain diverse environments.[489]

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[483] I have discussed the large-scale aspects of the above issues in Bosselman, *supra* note 13, at 236-325.

[484] Robert E. Bennetts et al., *Methods for Estimating Dispersal Probabilities and Related Parameters Using Marked Animals*, *in* DISPERSAL 3 (Jean Clobert et al. eds., 2001) ("In the study of population ecology, all population change results from births, deaths, immigration, and emigration.").

[485] *See* POTTS, *supra* note 70, at 45-78. We have mistakenly tended to think of natural systems in the condition we first studied them as having been "natural," ignoring what may have been a long history of fluctuations that occurred before that time. Jeremy B. C. Jackson, *What Was Natural in the Coastal Oceans?*, 98 PROC. NAT'L ACAD. SCI. 5411 (2001). *See generally* SETH R. REICE, THE SILVER LINING: THE BENEFITS OF NATURAL DISASTERS (2001).

[486] *See* Woodruff, *supra* note 101, at 5473 ("[N]ature can no longer be left alone to function, because our actions have doomed countless isolated populations to slow genetic decline and extirpation.").

[487] *See* discussion at notes 514-539 *infra*.

[488] Thompson et al., *supra* note 64, at 20. IMPLEMENTING ECOLOGICAL INTEGRITY: RESTORING REGIONAL AND GLOBAL ENVIRONMENTAL AND HUMAN HEALTH 52 (Phillipe Crabbé et al. eds., 2000) ("All national parks, reserves and other protection areas are changing as a result of external impacts. Steady-state ecosystems do not exist."). For a review of the history of attitudes toward environmental change, see Stan Godlovitch, *Things Change: So Whither Sustainability?*, 20 ENVTL. ETHICS 291 (1998).

[489] Some ecologists believe that species richness is greatest at an intermediate

Humans have accelerated the rate of change—sometimes gradually through increasing greenhouse gas emissions,[490] emitting toxic chemicals,[491] or expanding agriculture,[492] and sometimes rapidly by destroying wetlands[493] or tropical forests,[494]—but change has always been inevitable even absent human intervention.[495]

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level of disturbance. ROSENZWEIG, *supra* note 182, at 341-42; SHIGESADA & KAWASAKI, *supra* note 387, at 128. For a history of the "intermediate disturbance hypothesis," see Robert M. May, *The Effects of Spatial Scale on Ecological Questions and Answers*, *in* LARGE-SCALE ECOLOGY AND CONSERVATION BIOLOGY 1, 4 (P. J. Edwards et al eds., 1994). Some ecologists believe that an intermediate level of disturbance is also the level at which maximum evolution of new species occurs. Warren D. Allmon et al., *An Intermediate Disturbance Hypothesis of Maximal Speciation*, *in* BIODIVERSITY DYNAMICS: TURNOVER OF POPULATIONS, TAXA, AND COMMUNITIES 349 (Michael L. McKinney & James A. Drake eds., 1998). The intermediate disturbance theory is criticized in MUTSONORI TOKESHI, SPECIES COEXISTENCE: ECOLOGICAL AND EVOLUTIONARY PERSPECTIVES 280-81 (1999).

[490] Sala et al., *supra* note 179, at 1772 (predicting that climate change will be the primary cause of loss of biodiversity in northern latitudes). *See also* C. Drew Harvell et al., *Climate Warming and Disease Risks for Terrestrial and Marine Biota*, 296 SCI. 2158 (2002); Pain & Donald, *supra* note 393, at 159-68; Chris D. Thomas et al., *Extinction risk from climate change*, 427 NATURE 145 (2004) (large-scale models predict increased risk of extinctions caused by climate change).

[491] *See, e.g.*, Jan Ove Bustnes et al., *Ecological Effects of Organochlorine Pollutants in the Arctic: A Study of the Glaucous Gull*, 13 ECOLOGICAL APPLICATIONS 504 (2003) (documenting impact of buildup of organochlorine pollutants in the Arctic on the reproductive success of an arctic-breeding gull). *See generally* Pain & Donald, *supra* note 393, at 172-74; Maria Cone, *Of Polar Bears and Pollution*, LOS ANGELES TIMES, June 19, 2003, at 1.

[492] Sala et al., *supra* note 179, at 1770 (suggesting that in the tropics, changes in land use will be the major cause of loss of biodiversity).

[493] WILLIAM J. MITSCH & JAMES G. GOSSELINK, WETLANDS 4 (2d ed. 1993) (more than half of the wetlands in the United States have been drained).

[494] Stuart L. Pimm et al., *Can We Defy Nature's End?*, 293 NATURE 2207 (2001) ("Within half a century, tropical forests have shrunk by half . . . .").

[495] Peter M. Vitousek, *Community Turnover and Ecosystem Nutrient Dynamics*, *in* THE ECOLOGY OF NATURAL DISTURBANCE AND PATCH DYNAMICS 325, 333 (S. T. A. Pickett & P. S. White eds., 1985) (describing limited conditions under which ecological processes can maintain rough constancy). In many cases, lack of a long sequence of historical records may make it difficult to determine whether dramatic change in species composition is the result of human activities or part of a natural cycle. *See* Richard B. Aronson & William F. Precht, *Stasis, Biological Disturbance, and Community Structure of a Holocene Coral Reef*, 23 PALEOBIOLOGY 326 (1997) (use of core data to reconstruct history of coral composition); Robert E. Ricklefs & Eldredge Bermingham, *Nonequilibrium Diversity Dynamics of the Lesser Antillean Avifauna*, 294 SCI. 1522 (2001) (using phylogenetic methods to trace history of colonization of island chain by birds).

Disturbances such as wildfire, flood, and epidemic often play a key role in maintaining ecological functions.[496] Given the proper perspective, many of the things that our society has called "natural disasters" are a vital part of ecological processes.[497] Viewed at the proper scale, disturbances can be seen to be a necessary part of the ecological system and a stabilizing factor.[498] Unfortunately, as Duke University ecologist Norman Christensen has emphasized, the predictability of such disturbances is limited:

> Patterns of change are neither perfectly cyclic or linear. Rather successional transitions are often complex and patterns of disturbance and recovery are often greatly affected by "chance" events, that is, phenomena such as variations in weather that are controlled by factors external to the system being managed.[499]

Thus, in order to cope with disturbances in the past, species have had to evolve some degree of "resilience" to unpredictable

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[496] Steward Pickett and Peter White produced the pioneering synthesis of the important role of disturbance in ecology in 1985. *See generally* THE ECOLOGY OF NATURAL DISTURBANCE AND PATCH DYNAMICS (S.T.A. Pickett & P. S. White eds., 1985). For current confirmation of this thesis, see Dale et al., *supra* note 174, at 653 ("The type, intensity and duration of disturbance shape the characteristics of populations, communities, and ecosystems.").

[497] *See, e.g.*, Peter R. Grant et al., *Effects of El Niño Events on Darwin's Finch Productivity*, 81 ECOLOGY 2442 (2000) (stating that finches in the Galapagos breed prolifically in el niño years, but they also take into account the length of time since the last similar event; "[t]hus perturbations of natural systems can be fully understood only in a broad temporal context."). *See also* Anthony W. King, *Hierarchy Theory: A Guide to System Structure for Wildlife Biologists*, *in* WILDLIFE AND LANDSCAPE ECOLOGY: EFFECTS OF PATTERN AND SCALE 185, 208 (John A. Bissonette ed., 1997) (occasional collapse of a population may be found to be normal if viewed over a long time frame); Bruce McKay & Kieran Mulvaney, *A Review of Marine Major Ecological Disturbances*, 18 ENDANGERED SPECIES UPDATE 14 (2001) (stressing need to resolve the relative roles of natural and anthropogenic factors in causing major marine disturbances).

[498] R. V. O'NEILL ET AL., A HIERARCHICAL CONCEPT OF ECOSYSTEMS 163-69 (1986); LEVIN, *supra* note 39, at 112 (stating that forest modeling suggests local variability and heterogeneity provide the material for change; disturbance and renewal maintain the diversity). Analysis of any ecological system should include an analysis of its "disturbance regime." EPA, OFFICE OF FEDERAL ACTIVITIES, CONSIDERING ECOLOGICAL PROCESSES IN ENVIRONMENTAL IMPACT ASSESSMENTS 24-30 (1999).

[499] Norman L. Christensen, Jr., *Managing for Heterogeneity and Complexity on Dynamic Landscapes*, *in* THE ECOLOGICAL BASIS OF CONSERVATION: HETEROGENEITY, ECOSYSTEMS, AND BIODIVERSITY 167, 178 (Steward Pickett et al. eds., 1997).

environmental change.[500]

a. *Metapopulations*

Given the likelihood of environmental change, biologists have increasingly realized the need to understand how species have coped with past changes in the environment.[501] In doing so they have discovered that many species of plants and animals have evolved a "metapopulation" strategy for coping with environmental change.[502] They aggregate in clusters that are

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[500] University of Florida ecologist Crawford Holling says that many ecological systems exhibit cycles in which disturbance is a "release" from a brittle stability. Holling writes of a four-stage cycle, consisting of (1) colonization, in which rapidly reproducing species move in to take over vacant niches; (2) conservation, in which the colonizing species are joined by and eventually dominated by the "climax community;" (3) release, which takes place when the climax community is so dependent on conditions remaining constant that it becomes "brittle," inviting sudden environmental changes, such as disease or exotic species invasion, and (4) reorganization, in which the ecological system may either return to something approximating its earlier state or may collapse. C. S. Holling et al., *Science, Sustainability and Resource Management*, *in* LINKING SOCIAL AND ECOLOGICAL SYSTEMS: MANAGEMENT PRACTICES AND SOCIAL MECHANISMS FOR BUILDING RESILIENCE 342, 350-52 (Fikret Berkes et al. eds., 1998) (noting that chance plays a major role in determining which species will invade a disturbed area). *See also* C. S. Holling, *Cross-scale Morphology, Geometry, and Dynamics of Ecosystems*, 62 ECOLOGICAL MONOGRAPHS 447, 480-81 (1992); C. S. Holling, *Resilience and Stability of Ecological Systems*, 4 ANN. REV. OF ECOLOGY AND SYSTEMATICS 1 (1973). If the ecological system has little resilience, some disturbances can carry the ecological system into "quite different stability domains—for example, fire can transform mixed grass and tree savannas into shrub dominated semideserts . . . ." C. S. Holling, *Biodiversity in the Functioning of Ecosystems: An Ecological Synthesis*, *in* BIODIVERSITY LOSS: ECONOMIC AND ECOLOGICAL ISSUES 44, 60-61 (Charles Perrings et al. eds., 1995) [hereinafter *Biodiversity Functioning*]. For a discussion of the reorganization of the ecological systems after the Mount St. Helens eruption, see Monica G. Turner et al., *Fires, Hurricanes, and Volcanoes: Comparing Large Disturbances*, 47 BIOSCIENCE 758 (1997). The concept of resilience, and its various usages, is reviewed in Lance H. Gunderson, *Ecological Resilience: In Theory and Application*, 31 ANN. REV. OF ECOLOGY AND SYSTEMATICS 425 (2000).

[501] *See, e.g.*, Niles Eldredge, *Where the Twain Meet: Causal Intersections Between the Genealogical and Ecological Realms*, *in* SYSTEMATICS, ECOLOGY AND THE BIODIVERSITY CRISIS 1, 12 (Niles Eldredge ed., 1992) (stating that "eurytopes," wide-ranging species, are most prevalent in areas where there is great environmental variation over the year).

[502] Biologists use the term "population" to mean a group of individuals of the same species living in the same habitat area. A DICTIONARY OF ECOLOGY, *supra* note 243, at 324. If different populations of the same species occupy separate habitat patches within the same general area, the aggregate of such clusters is called a "metapopulation." Thus metapopulation is defined as "[a] group of

separated from other clusters of individuals of the same species, but retain a certain amount of interaction with the other clusters.[503]

Wetland species, for example, often form metapopulations because wetlands tend to be scattered around the landscape, enlarging and contracting as environmental conditions change, silting up in one place and re-forming somewhere else.[504] For the organisms that inhabit the wetlands, it "is the fate of these local populations to wink off and on over time."[505] Many forest species also use metapopulation strategies because storms and fires create forest gaps that disappear as trees mature, while new storms, fires, or insect infestations create new gaps elsewhere.[506]

Metapopulation ecologists study the way that metapopulations change and move over decades, centuries, and millennia.[507] Most species that exist today have been in existence through many changes in their environmental conditions.[508] Many species have learned to live in patches of habitat that change their locations over relatively short time spans and that interact at close range with other kinds of habitat.[509] Research into the adaptations by species

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conspecific populations that exist at the same time, but in different places." *Id.* at 259.

[503] ROBERT E. RICKLEFS, THE ECONOMY OF NATURE 362-63 (4th ed. 1996).

[504] *See* Alyson C. Flournoy, *Preserving Dynamic Systems: Wetlands, Ecology and Law*, 7 DUKE ENVTL. L. & POL'Y FORUM 105, 114 (1996).

[505] NOSS & COOPERRIDER, *supra* note 112, at 61-62.

[506] LEVIN, *supra* note 39, at 120-21; O'NEILL ET AL., *supra* note 498, at 86.

[507] *See, e.g.*, C. C. Vos et al., *Toward Ecologically Scaled Landscape Indices*, 183 AMER. NATURALIST 24 (2001); John A. Vucetich et al., *Population Variability and Extinction Risk*, 14 CONSERVATION BIOLOGY 1704, 1705, 1711 (2000).

[508] *See* POTTS, *supra* note 70, at 45-78.

[509] Fragments are not islands in a hostile environment. Species interact with neighboring patches of other habitats. Fragmentation is dynamic. The fragments change and species move in response. John A. Wiens, *Habitat Fragmentation: Island v. Landscape Perspectives on Bird Conservation*, 137 IBIS S97, S99-S100 (1994). Early metapopulation models, which assumed that habitat fragments were isolated in "an idealized, spatially homogeneous and temporally constant natural background," often proved unrealistic as applied on the ground. Yrjö Haila, *A Conceptual Genealogy of Fragmentation Research: From Island Biogeography to Landscape Ecology*, 12 ECOLOGICAL APPLICATIONS 321, 326, 329 (2002). Pickett et al., *supra* note 207, at 49 (suggesting that the island-ocean model is obsolete). Some landscape ecologists question whether recent studies that attribute increases in dispersal to habitat fragmentation have overlooked high rates of pre-fragmentation dispersal that were never found because population studies were not large enough in scale. Gray Merriam, *Movement in Spatially Divided Populations: Responses to Landscape Structure*, *in* LANDSCAPE

in metapopulations to the dynamic aspect of their habitat has provided new insight on the local survival or extinction of particular species.[510] We know that in order to avoid extinctions each species must be prepared to adapt to change in regard to at least three key functions: (1) staying alive (or as the biologists would say, regulating mortality); (2) reproducing; and (3) exploring new territory (dispersing).[511] Even if we succeed with our traditional methods of reducing mortality,[512] and if we successfully explore more ways to control threats to reproduction,[513] it may not be sufficient to save some of the species that lack adequate dispersal mechanisms.

b. *Dispersal*

Biologists know that the ability of clustered populations to exchange individuals or genes with other populations has an important effect on their potential survival when environmental conditions change.[514] A species accomplishes this exchange

APPROACHES IN MAMMALIAN ECOLOGY AND CONSERVATION 64, 65 (William Z. Lidicker Jr. ed., 1995).

[510] One branch of this study is known as "metapopulation ecology," which has attracted a great deal of attention in the last two decades. *See* ILKKA HANSKI, METAPOPULATION ECOLOGY 1-3 (1999). *See also* Peter H. Thrall et al., *The Metapopulation Paradigm: A Fragmented View of Conservation Biology*, *in* GENETICS, DEMOGRAPHY AND VIABILITY OF FRAGMENTED POPULATIONS 75 (Andrew G. Young & Geoffrey M. Clarke eds., 2000).

[511] Bennetts et al., *supra* note 484.

[512] The traditional way that humans have tried to increase the population of a species is by regulating or forbidding the killing of individual members of the species. For a concise review of our complex history of regulating wildlife in this way, see GOBLE & FREYFOGLE, *supra* note 113, at 762-970, 1216-43, 1287-1310.

[513] Rachel Carson called attention to the impact of our chemicals on animal reproduction forty years ago. RACHEL CARSON, SILENT SPRING 108-22 (1962). More recently, scientists are concerned about the effects of a popular herbicide on the reproductive capabilities of frogs and other amphibians. Ben Harder, *Feminized Frogs: Herbicide Disrupts Sexual Growth*, 161 SCI. NEWS 243 (2002).

[514] Hanski & Simberloff, *supra* note 376, at 6. Nicolas Perrin & Jérôme Goudet, *Inbreeding, Kinship, and the Evolution of Natal Dispersal*, *in* DISPERSAL 123, 126-27 (Jean Clobert et al. eds., 2001) (reviewing how some authors suggest that dispersal evolved as a way of avoiding inbreeding, but others believe that this was only a marginally relevant cause). Some species of plants and animals are relatively adaptable to changing environmental conditions because they occupy a relatively widespread niche in the environment that allows them to vary their reproductive behavior in response to environmental conditions. For example, the various species of Galapagos finches have little interspecific

through dispersal—movement of individual organisms away from their site of origination.[515] It is dispersal that "gives populations, communities, and ecosystems their characteristic texture in space and time."[516]

Dispersal takes many forms; for example, plants often rely on the wind or birds to disperse their seeds,[517] and many animals typically drive away their mature young to colonize new habitat areas.[518] Much dispersal is unsuccessful, in the sense that the area at which the species arrives is unsuitable as a place in which it can reproduce and prosper—think of the millions of cottonwood or

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competition and vary their breeding behavior in sophisticated ways in response to climate variation. Grant et al., *supra* note 497, at 2442.

[515] *See* A DICTIONARY OF ECOLOGY, *supra* note 243, at 124. For an interesting early discussion of the role of dispersal in the expansion of bird populations, see Joseph Grinnell, *The Role of the "Accidental,"* 39 THE AUK 373 (1922).

[516] John A. Wiens, *The Landscape Context of Dispersal*, *in* DISPERSAL 96, 97 (Jean Clobert et al. eds., 2001). Peter Waser makes an amusing and useful analogy to certain human dispersal patterns:

> Because the range of ideas and systems discussed in this book is so broad, readers might well question whether dispersal is a unitary phenomenon. Academics, like other species, disperse, and the dispersal of academics seems parallel in many regards to other cases of dispersal discussed in this book. Suppose we could determine what mix of academic kin competition and inbreeding avoidance leads to the observed dispersal rates, what patterns of patch choice, interpatch movement and demographic stochasticity lead to the observed dispersal distributions, or what patterns of academic dispersal maximize population persistence. Would we expect the answers to be generalizable to other species? Each reader will have to decide whether a grand unified theory of dispersal is on the horizon.

Peter Waser, *Foreword to* DISPERSAL ix, x (Jean Clobert et al. eds., 2001).

[517] Oliver Tackenberg et al., *Assessment of Wind Dispersal Potential in Plant Species*, 73 ECOLOGICAL MONOGRAPHS 191, 202 (2003) ("Dispersal potential should be considered in the risk assessment of plant species as dispersal may regulate the dynamics and long-term survival of metapopulations . . . .") (citation omitted); Ove Eriksson & Anna Jakobsson, *Recruitment Trade-offs and the Evolution of Dispersal Mechanisms in Plants*, 13 EVOLUTIONARY ECOLOGY 411, 414-17 (1999) (reviewing factors that influence seed size and quantity).

[518] *See* KREBS, *supra* note 355, at 46-60 (describing varieties of dispersal). The literature increasingly includes detailed dispersal studies. *See, e.g.*, Andrew M. Baker et al., *Evidence for Long-Distance Dispersal in a Sedentary Passerine, Gymnorhina tibicen (*Artamidae*)*, 72 BIOL. J. OF THE LINNAEAN SOC'Y 333, 334 (2001); David R. Breininger & Geoffrey M. Carter, *Territory Quality Transitions and Source-Sink Dynamics in a Florida Scrub-Jay Population*, 13 ECOLOGICAL APPLICATIONS 516 (2003). For a discussion of some of these studies, see James Gorman, *In Some Bird Species, Little Chance for an Empty Nest*, N.Y. TIMES, Oct. 29, 2002, at F3.

maple seeds that are deposited on lawns each year.[519] Such areas are known as "sinks," because the species cannot survive there without continual immigration.[520] But in some cases, the dispersing species will find a hospitable new home, which may then become a "source" for future dispersal elsewhere.[521] Ecological resilience is fostered by population levels which maintain enough surplus to allow dispersal to respond to changing environmental conditions.[522] This provides room for populations of particular species to rise and fall over time, and thus enables the ecological systems to adapt to environmental change without any drastic change in the mix of species.[523] Niles Eldredge describes each separate population of a species as a "genetic reservoir" whose reproduction renews the supply of players in the local ecological arena and also supplies players to other arenas in need of colonization. For example, moose, which had been exterminated from the Adirondacks years ago, are becoming reestablished through migration from Canada and Vermont.[524]

The importance of dispersal has long been recognized,[525] but

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[519] *See generally* WILLIAMSON, *supra* note 388, at 28-54.

[520] Vincent A. A. Jansen & Jin Yoshimura, *Populations Can Persist in an Environment Consisting of Sink Habitats Only*, 95 PROC. NAT'L ACAD. SCI. 3696, 3696 (1998). To further complicate the terminology, some areas are referred to as "pseudo-sinks" if they would not support their current population without immigration, but would appear to support a smaller but stable population. Ilkka Hanski, *Population Dynamic Consequences of Dispersal in Local Populations and in Metapopulations*, *in* DISPERSAL 283, 290 (Jean Clobert et al. eds., 2001).

[521] H. Ronald Pulliam, *Sources, Sinks, and Population Regulation*, 132 AMER. NATURALIST 652 (1988). The scale of this process may vary greatly. One study suggests that speciation and dispersal of reef fish from a source area between Indonesia and the Philippines is responsible for reef fish diversity patterns throughout the Pacific and Indian Oceans. Camilo Mora et al., *Patterns and Processes in Reef Fish Diversity*, 421 NATURE 933, 934 (2003).

[522] Solbrig, *supra* note 119, at 110-11 (stating that species richness is important during periods of environmental fluctuation); Susan Hanna & Svein Jentoft, *Human Use of the Natural Environment: An Overview of Social and Economic Dimensions*, *in* RIGHTS TO NATURE: ECOLOGICAL, ECONOMIC, CULTURAL, AND POLITICAL PRINCIPLES OF INSTITUTIONS FOR THE ENVIRONMENT 35, 42 (Susan S. Hanna et al. eds., 1996).

[523] Holling, *Biodiversity Functioning*, *supra* note 500, at 44, 80-83. *See also*, Erin M. Bayne & Keith A. Hobson, *Apparent Survival of Male Ovenbirds in Fragmented and Forested Boreal Landscapes*, 83 ECOLOGY 1307, 1312-15 (2002) (arguing that dispersal of younger birds makes up for lower nesting success in small forest fragments).

[524] NILES ELDREDGE, REINVENTING DARWIN 194-95 (1995).

[525] The importance of dispersal was recognized as early as the pioneering

research has proven to be difficult because of the problem of tracking huge numbers of organisms,[526] and because dispersal takes place in complex, heterogeneous milieus.[527] New technology is helping; DNA analysis makes it possible to estimate some dispersal abilities by measuring the extent to which genetic material travels among separate populations.[528] Field studies with marked animals show that the path and rate of dispersal can be highly dependent on the characteristics of the intervening landscape,[529] and that animals select new habitat using a wide

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1927 ecology treatise of Charles Elton. *See* Mathew A. Leibold & J. Timothy Wooten, *Introduction to* CHARLES ELTON, ANIMAL ECOLOGY xix, xli (rev. ed. 2001).

[526] Hanski, *supra* note 520, at 283-84; J. D. Brawn & S. K. Robinson, *Source-Sink Population Dynamics May Complicate the Interpretation of Long-Term Census Data*, 77 ECOLOGY 3, 10 (1996). Models of the dynamics of species in complex landscapes move individuals around on maps of actual habitat, but this "can suggest false exactitude" because though it easy to map vegetation "it is extraordinarily difficult to obtain information on dispersal behavior." Kareiva & Wennergren, *supra* note 409. *See also* Kevin J. Gaston & William E. Kunin, *Rare-Common Differences: An Overview*, *in* THE BIOLOGY OF RARITY: CAUSES AND CONSEQUENCES OF RARE-COMMON DIFFERENCES 12, 16 (William E. Kunin & Kevin J. Gaston eds., 1997); Ulf Dieckmann et al., *The Evolutionary Ecology of Dispersal*, 14 TRENDS IN ECOLOGY AND EVOLUTION 88 (1999); MCPHERSON & DESTEFANO, *supra* note 408, at 39.

[527] Wiens, *supra* note 516, at 108. *See, e.g.*, Ottar N. Bjørnstad et al., *Waves of Larch Budmoth Outbreaks in the European Alps*, 298 SCI. 1020, 1020 (2002) (attempting to predict cyclical pattern of moth dispersal); Michal Kozakiewicz & Jakub Szacki, *Movements of Small Mammals in a Landscape: Patch Restriction or Nomadism?*, *in* LANDSCAPE APPROACHES IN MAMMALIAN ECOLOGY AND CONSERVATION 78, 79-80 (William Z. Lidicker Jr. ed., 1995) (stating that past studies of dispersal of small mammals have underestimated dispersal distances); GASTON, *supra* note 274, at 113-14 (stating that studies of dispersal sometimes rely on proxy measures of dispersal ability, some of which are questionable).

[528] Robert E. Bennetts et al., *supra* note 484. *See also* Marie L. Hale et al., *Impact of Landscape Management on the Genetic Structure of Red Squirrel Populations*, 293 SCI. 2246, 2246-47 (2001) (DNA tests on museum specimens of various ages show how increasing forest connectivity over time improved gene flow throughout the metapopulation).

[529] Wiens, *supra* note 516, at 99-101. As the intervening landscape undergoes changes, the dispersal patterns also change. *Id*. at 104-08. Sources may become sinks and sinks may become sources. Paul Opdam & John A. Wiens, *Fragmentation, Habitat Loss and Landscape Management*, *in* CONSERVING BIRD DIVERSITY: GENERAL PRINCIPLES AND THEIR APPLICATION 203, 211 (Ken Norris & Deborah J. Pain eds., 2002); John Vandermeer, *Agricultural Scientists are Wrong about Agriculture and Conservation Scientists are Wrong about Conservation*, 20 ENDANGERED SPECIES UPDATE 53, 61 (2003) (habitats that are now lacking in biodiversity may be very important passageways for the habitats that are biodiversity rich).

variety of cues, including presence of members of the same or compatible species, absence of predators, or habitat similar to that in which the animal originated.[530] As metapopulation ecologists have begun building increasingly realistic models to predict the behavior of clusters of individual species in response to future environmental changes,[531] they realized the importance of dispersal methods to the processes that allow species to survive.[532] For metapopulations to survive, the recolonization rate must exceed local extinction rates.[533] Conservation biologists often find that even a "trickle of dispersal" may be enough to make the difference in whether a population stays viable.[534] And with prospects for ever more rapid environmental change, dispersal is taking on heightened importance.[535]

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[530] Judy A. Stamps, *Habitat Selection by Dispersers: Integrating Proximate and Ultimate Approaches*, *in* DISPERSAL 230, 233-42 (Jean Clobert et al. eds., 2001). Many species have complex dispersal strategies in which many factors are considered. Ophélie Ronce et al., *Perspectives on the Study of Dispersal Evolution*, *in* DISPERSAL 341, 346 (Jean Clobert et al. eds., 2001).

[531] *See, e.g.*, Ilkka Hanski, *Predictive and Practical Metapopulation Models: The Incidence Function Approach*, *in* SPATIAL ECOLOGY: THE ROLE OF SPACE IN POPULATION DYNAMICS AND INTERSPECIFIC INTERACTIONS 21, 22 (David Tilman & Peter Kareiva eds., 1997). Dispersal of some organisms may be "aided by, or dependent upon, close physical association with other species." Lisa R. Belyea & Jill Lancaster, *Assembly Rules Within a Contingent Ecology*, 86 OIKOS 402, 412 (1999).

[532] Pickett & Rogers, *supra* note 211, at 112, 116. *See also* Ran Nathan, *Dispersal Biogeography*, 2 ENCYCLOPEDIA OF BIODIVERSITY 127, 130 (Simon A. Levin ed., 2001).

[533] Peter Chesson, *Metapopulations*, 4 ENCYCLOPEDIA OF BIODIVERSITY 161, 174 (Simon A. Levin ed., 2001). Much of the early work on metapopulations took advantage of the theory of island biogeography developed by MacArthur and Wilson, but better long-range technologies have made more sophisticated applications possible. *See* WHITTAKER, *supra* note 179, 221-27 (1998). Wiens, *supra* note 509, at S101 (early metapopulation models have been criticized as overly simplistic). *See also* Mark Lomolino & David R. Perault, *Island Biogeography and Landscape Ecology of Mammals Inhabiting Fragmented, Temperate Rainforests*, 10 GLOBAL ECOLOGY & BIOGEOGRAPHY 113 (2001) (empirical studies of forest patches produced results inconsistent with island biogeography theory).

[534] Macdonald & Johnson, *supra* note 437.

[535] For a critique of metapopulation analysis that questions the extent to which it accurately represents the real structure of metapopulations, see Susan Harrison, *Do Taxa Persist as Metapopulations in Evolutionary Time?*, *in* BIODIVERSITY DYNAMICS: TURNOVER OF POPULATIONS, TAXA, AND COMMUNITIES 19 (Michael L. McKinney & James A. Drake eds., 1998). *See also* Daniel Simberloff, *Biogeographic Approaches and the New Conservation Biology*, *in* THE ECOLOGICAL BASIS OF CONSERVATION: HETEROGENEITY, ECOSYSTEMS, AND

Those organisms that have good dispersal abilities may be at less risk from habitat destruction than other species, including even those species that are currently dominant.[536] Metapopulation models often suggest that the species most likely to become extinct are not necessarily the rarest species, but those that are the poorest dispersers.[537] In other words, those species that fail to adapt to environmental change by moving to new habitats may be at risk even though they are superior competitors and have become abundant in their current environment.[538] This suggests that current numbers of individuals of a species may not be a key to long-term biodiversity, and that the status of local biodiversity at any given time may not be a satisfactory predictor of post-disturbance biodiversity.[539]

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BIODIVERSITY 274, 280 (Steward Pickett et al. eds., 1997) (discussing the ambiguity of appearance of a metapopulation, which may be a dwindling species or the result of a failure of metapopulation dynamics).

[536] David Tilman et al., *Habitat Destruction and the Extinction Debt*, 371 NATURE 65, 65-66 (1994). *See also* John A. Wiens, *Landscape Mosaics and Ecological Theory*, *in* MOSAIC LANDSCAPES AND ECOLOGICAL PROCESSES 1, 10-12 (Lennart Hansson et al. eds., 1995) (dispersal is the key to the dynamical behavior of metapopulation models).

[537] Luc Lens et al., *Avian Persistence in a Fragmented Rainforest*, 298 SCI. 1236 (2002). *See also* Tokeshi, *supra* note 489, at 328-33; Nathan, *supra* note 532, at 150.

[538] Tilman & Lehman, *supra* note 403, at 241-42, 249 ("This effect, predicted by metapopulation-like models, was found to be remarkably robust when explored using explicitly spatial simulations.") *See also* Hanski, *supra* note 520, at 284, 291-93 (dispersal is a form of risk-spreading). However, species that have invested heavily in dispersal ability may have traded off competitiveness, fecundity, or longevity. Tokeshi, *supra* note 489, at 330; Jamie M. Kneitel & Jonathan M. Chase, *Trade-Offs in Community Ecology: Linking Spatial Scales and Species Coexistence*, 7 ECOLOGY LETTERS 69, 69 (2004) (finding the benefits of performing one ecological function well comes at the cost of performing another function less well). *See also* Symstad & Tilman, *supra* note 369, at 424 (finding tradeoffs among competitiveness and dispersal in small-scale plant experiments).

[539] Federico Cheever, *From Population Segregation to Species Zoning: The Evolution of Reintroduction Law Under Section 10(J) of the Endangered Species Act*, 1 WYO. L. REV. 287, 290-91, 365-69 (2001) (arguing that current reintroduction practices may increase current biodiversity at the expense of future biodiversity). *See also* David W. Burnett, *New Science But Old Laws: The Need to Include Landscape Ecology in the Legal Framework of Biodiversity Protection*, 23 ENVIRONS ENVTL. L. & POL'Y J. 47, 55 (1999).

c. *Habitat heterogeneity*

Many ecologists fear that the current emphasis on protecting only large reserves of homogeneous habitat[540] may be ignoring the need for organisms to be able to disperse to a variety of habitats over both space and time.[541] The preference for homogeneous reserves has relied heavily on studies of forest birds in the United States.[542] Ironically, perhaps, the growth of forest in the Eastern states has been so significant that some of the birds living at the forest edge are now declining rather rapidly.[543] Patchy landscapes offer the possibility of regional coexistence of species in spite of local extinctions.[544]

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[540] For an example of the prevailing emphasis on large reserves, see CONTINENTAL CONSERVATION: SCIENTIFIC FOUNDATIONS OF REGIONAL RESERVE NETWORKS (Michael E. Soulé & John Terborgh eds., 1999).

[541] *See* JAMES H. BROWN & MARK V. LOMOLINO, BIOGEOGRAPHY 565 (2d ed. 1998) (concluding that it is not clear whether large reserves or small reserves better protect biodiversity). Vandermeer, *supra* note 529, at 61 ("When the history of how we saved the world's biodiversity is written, probably very little will be written about biological preserves. Almost all the story will be about how we got our act together to readjust our managed ecosystems in light of the need to preserve biodiversity."). *See also* Larry D. Harris et al., *Landscape Processes and Their Significance to Biodiversity Conservation*, *in* POPULATION DYNAMICS IN ECOLOGICAL SPACE AND TIME 319, 323, 339 (Olin E. Rhodes, Jr. et al. eds., 1996).

[542] *See, e.g.*, Chandler S. Robbins et al., *Habitat Area Requirements of Breeding Forest Birds in the Middle Atlantic States*, 103 WILDLIFE MONOGRAPHS 6, 7 (1989); H. J. Weinberg & R. R. Roth, *Forest Area and Habitat Quality for Nesting Wood Thrushes*, 115 THE AUK 879, 879-80 (1998); C. Roberts & C. J. Norment, *Effects of Plot Size and Habitat Characteristics on Breeding Success in Scarlet Tanagers*, 116 THE AUK 73, 73 (1999); Kenneth V. Rosenberg et al., *Effects of Forest Fragmentation on Breeding Tanagers: A Continental Perspective*, 13 CONSERVATION BIOLOGY 568, 569 (1999). *See also* Melissa D. Vance et al., *Effect of Reproductive Rate on Minimum Habitat Requirements of Forest-Breeding Birds*, 84 ECOLOGY 2643, 2643 (2003) (forest birds with high reproduction rates need less habitat than those with low reproduction rates).

[543] ROBERT A. ASKINS, RESTORING NORTH AMERICA'S BIRDS: LESSONS FROM LANDSCAPE ECOLOGY 1-42 (2000). *See also* M.K. Trani et al., *Patterns and Trends of Early Successional Forests in the Eastern United States*, 29 WILDLIFE SOCIETY BULLETIN 413, 414 (2001); W.C. Hunter et al., *Conservation of Disturbance-Dependent Birds in Eastern North America*, 29 WILDLIFE SOCIETY BULLETIN 440, 453-54 (2001); J.A. Litvaitis, *Importance of Early Succesional Habitats to Mammals in Eastern Forests*, 29 WILDLIFE SOCIETY BULLETIN 466, 467 (2001); F.R. Thompson III & R.M. DeGraaf, *Conservation Approaches for Woody, Early-Successional Communities in the Eastern United States*, 29 WILDLIFE SOCIETY BULLETIN 483, 483-85 (2001).

[544] HUSTON, *supra* note 361, at 88. *See also* Bayne & Hobson, *supra* note 523, at 1312-15 (arguing that dispersal of younger birds makes up for lower

Today ecologists recognize that "landscape heterogeneity is an important component for the persistence and abundance of many species."[545] Historical research has shown that many areas that early European settlers called unbroken wilderness were actually quite patchy.[546] Similarly, as biologists have made more detailed analyses of current conditions in tropical forests, they also tend to find more patchiness than in the old popular image of the "jungle."[547]

A review of recent research by Carleton University ecologist Lenore Fahrig casts doubt on the idea that heterogeneity of habitat always affects biodiversity adversely; it shows that in regard to birds, at least, habitat fragmentation may have both positive and

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nesting success in small forest fragments); David B. Lindenmayer et al., *Effects of Forest Fragmentation on Bird Assemblages in a Novel Landscape Context*, 72 ECOLOGICAL MONOGRAPHS 1, 14 (2002) (many native Australian birds are more frequent in eucalyptus fragments than in continuous eucalyptus forest); Jeremy W. Lichstein et al., *Landscape Effects of Breeding Songbird Abundance in Managed Forests*, 12 ECOLOGICAL APPLICATIONS 836, 836 (2002) (songbird abundance will reflect the quantity of different habitats in the landscape rather than the spatial arrangement of those habitats); Pierre Drapeau et al., *Landscape-Scale Disturbances and Changes in Bird Communities of Boreal Mixed-Wood Forests*, 70 ECOLOGICAL MONOGRAPHS 423, 437 (2003) (patterns of bird community composition were not related to amount of edge or interior habitat); Samuel A. Cushman & Kevin McGarigal, *Landscape-Level Patterns of Avian Diversity in the Oregon Coast Range*, 73 ECOLOGICAL MONOGRAPHS 259 (2003) (species richness found to be minimal in unbroken mature forest); John P. Hayes et al., *Response of Birds to Thinning Young Douglas-Fir Forests*, 13 ECOLOGICAL APPLICATIONS 1222 (2003) (short-term results of thinning are positive, neutral, or of minor negative impact for most bird species). These studies contrast with the prevailing view among conservation biologists that it is primarily species of the deep forest that need protection because species of the forest edge are usually common and widespread. *See* NAT'L RESEARCH COUNCIL, *supra* note 19, at 27.

[545] Lenore Fahrig, *Effect of Habitat Fragmentation on the Extinction Threshold: A Synthesis*, 12 ECOLOGICAL APPLICATIONS 346, 352 (2002). *See also* Lenore Fahrig, *Effects of Habitat Fragmentation on Biodiversity*, 34 ANN. REV. OF ECOLOGY, EVOLUTION AND SYSTEMATICS 487 (2003); Kozakiewicz & Szacki, *supra* note 527, at 83-86 (stating that, "long distance movements and nomadism are adaptations to landscape variability in space and time"); MCPHERSON & DESTEFANO, *supra* note 408, at 121 (illustrating that in eastern North America, biologists are concerned about the loss of early successional communities both from natural succession and lack of fire, mowing, or other disturbance).

[546] *See, e.g.*, ANTHONY GODFREY, BUREAU OF INDIAN AFFAIRS, A FORESTRY HISTORY OF TEN WISCONSIN INDIAN RESERVATIONS UNDER THE GREAT LAKES AGENCY: PRECONTRACT TO PRESENT 4 (1996).

[547] S. Joseph Wright, *Plant Diversity in Tropical Forests: A Review of Mechanisms of Species Coexistence*, 130 OECOLOGIA 1, 7 (2002).

negative effects.[548] An extensive study of butterflies in Borneo also concluded that "future management to reduce impacts of logging on biodiversity should aim to preserve environmental heterogeneity as far as possible . . . ."[549] The heterogeneous landscapes also may often serve as a barrier to the rapid spread of pathogens, fire or other disturbance.[550] The rate of change in landscape pattern, and the opportunity for organisms to find patches of habitat of various sizes, may be important factors in assuring survival of populations.[551]

Although the growing recognition of the value of heterogeneity is an important advance in ecological science, it is important not to carry the idea to the same extremes that characterized some of the advocates of large homogeneous reserves.[552] What we now know is that the effects of disturbance on natural habitats should not be characterized in black-and-white terms because the impacts are highly dependent on both local and

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[548] Fahrig, *supra* note 545, at 351. *See also* Opdam & Wiens, *supra* note 529, at 206 (natural patch dynamics may have resulted in adaptation to fragmentation that carries over to human disturbance: "The assumption that an observed change in landscape pattern is the cause of an observed change in bird abundance or distribution should be tested rather than accepted uncritically."); Fiedler et al., *supra* note 247, at 88 (suggesting that the problem of habitat fragmentation is even more complex than ecologists had envisioned); Jan Bogaert, *Lack of Agreement on Fragmentation Metrics Blurs Correspondence between Fragmentation Experiments and Predicted Effects*, 7 CONSERVATION ECOLOGY 1, r6 (2003) (illustrating difficulties of defining fragmentation).

[549] K.C. Hamer et al., *Ecology of Butterflies in Natural and Selectively Logged Forests of Northern Borneo: The Importance of Habitat Heterogeneity*, 40 J. OF APPLIED ECOLOGY 150, 158 (2003). The study found that unlogged forest not only contained habitat for species that need deep shade but it also provided habitat for those species that need open gaps created by fallen trees. Both of these types of habitat were rare in selectively logged forest. *Id*. at 157.

[550] Macdonald & Johnson, *supra* note 437, at 363-64.

[551] Susan Harrison & Lenore Fahrig, *Landscape Pattern and Population Conservation, in* MOSAIC LANDSCAPES AND ECOLOGICAL PROCESSES 295, 297, 304 (Lennart Hansson et al. eds., 1995). *See, e.g.*, Scott A. Morrison & Douglas T. Bolger, *Lack of an Edge Effect on Reproduction in a Fragmentation-Sensitive Sparrow*, 12 ECOLOGICAL APPLICATIONS 398, 398 (2002) ("contrary to our expectations, the ground-nesting Rufous-crowned sparrow . . . did not suffer from higher nest predation . . . adjacent to the urban edge."). *See also* Haila, *supra* note 509, at 329 (the analogy of refuges to islands is highly questionable); Pickett et al., *supra* note 207, at 49 ("The island-ocean model, an extreme form of the simple contrast between patch and matrix, has been superseded in patch dynamics.").

[552] MICHAEL A. ROSENZWEIG, WIN-WIN ECOLOGY: HOW THE EARTH'S SPECIES CAN SURVIVE IN THE MIDST OF HUMAN ENTERPRISE 143-52 (2003).

regional conditions.[553] To generalize that heterogeneity enhances biodiversity is an oversimplification at least as misleading as the wholesale condemnation of fragmentation.[554]

**PUZZLE #10:**
**DO WE NEED TO GIVE SPECIAL PRIORITY TO THOSE SPECIES THAT ARE LIKELY TO HAVE DIFFICULTY IN DISPERSING TO APPROPRIATE HABITATS IN RESPONSE TO ENVIRONMENTAL CHANGE?**

2. *Speciation as a source of biodiversity*

Evolution of a new species increases species richness.[555] Evolution is naturally creating new species all the time, and at a faster pace than scientists had realized until recently.[556] Should we encourage such speciation or discourage it? What if the new species pose dangers to our health or productivity? And even more controversially, should we use genetic engineering to speed up the process of speciation?

a. *Diversity through natural selection*

The diversity of species that we now have is the result of

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[553] John A. Bissonette & Ilse Storch, *Fragmentation: Is the Message Clear?*, 6 CONSERVATION ECOLOGY 2, 14 (2002) (effects of fragmentation depend greatly on the temporal and spatial scales of observation). Under the ESA, the designation of "critical habitat" has proven to be a perplexing issue, but one beyond the scope of this article. *See* STAN. ENVTL. L. SOC'Y, THE ENDANGERED SPECIES ACT 59-71 (2001). For a history of the controversy, see RICHARD TOBIN, THE EXPENDABLE FUTURE: U.S. POLITICS AND THE PROTECTION OF BIOLOGICAL DIVERSITY 175-80 (1990).

[554] John A. Wiens, *Ecological Heterogeneity: An Ontogeny of Concepts and Approaches*, *in* THE ECOLOGICAL CONSEQUENCES OF ENVIRONMENTAL HETEROGENEITY 9, 25 (M.J. Hutchings et al. eds., 1999).

[555] NAT'L RESEARCH COUNCIL, *supra* note 55, at 22. *See generally* Hope Hollocher, *Theories of Speciation*, 5 ENCYCLOPEDIA OF BIODIVERSITY 383 (Simon A. Levin ed., 2001) (explaining concepts of speciation and evolutionary forces).

[556] Nicholas H. Barton, *Speciation*, 16 TRENDS IN ECOLOGY AND EVOLUTION 325 (2001) ("The past few years have seen a resurgence of interest in speciation . . . ."). *See* Anurag A. Agrawal, *Community Genetics: New Insights into Community Ecology by Integrating Population Genetics*, 84 ECOLOGY 543 (2003) (introducing a special feature with articles on the interaction between genes within a species and populations of other species in a community.)

speciation that took place in the past.[557] Molecular biology and microbiology have made us much more aware of the continuing role of speciation in enhancing biodiversity,[558] sometimes in ways that cause concern.[559]

Many evolutionary biologists believe that most speciation is "allopatric," which means that it begins when a population of a species is isolated from the main body of the species and develops special adaptations to the local environment.[560] There is an increasing awareness that such speciation can take place quite rapidly in response to environmental change,[561] and that some types of organisms are more likely to develop new species than others.[562]

Recent research is beginning to suggest that speciation can take place without geographic separation if different populations develop specialized ecological niches.[563] Evidence is

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[557] Wilson, *supra* note 148, at 22.

[558] Five major factors are indicated by the biological research to be involved in the rise of biodiversity among organisms: mutation, natural selection, genetic drift, geographic separation, and genetic recombination. HEY, *supra* note 148, at 13. In relatively few cases, however, have the roles of each of these factors been clarified. *Id*.

[559] STEPHEN R. PALUMBI, THE EVOLUTION EXPLOSION: HOW HUMANS CAUSE RAPID EVOLUTIONARY CHANGE 9-10, 35-36 (2001) (development of resistance to antibiotics and pesticides through speciation).

[560] BRUCE S. LIEBERMAN, PALEOBIOGEOGRAPHY 63-71 (2000); DOLPH SCHULTER, ADAPTIVE RADIATION 21-30 (2000). The isolation that creates the condition for this type of speciation usually comes about either because of major geophysical change (such as a glacier splitting two populations of a species) or because a population settles on an island or other isolated location on the periphery of the species' range. BROOKS & MCLENNAN, *supra* note 254, at 116-23.

[561] John N. Thompson, *Rapid Evolution as an Ecological Process*, 13 TRENDS IN ECOLOGY AND EVOLUTION 329 (1998) (analyzing studies of rapid evolutionary change in links between species); JOHN A. ENDLER, NATURAL SELECTION IN THE WILD 129-54 (1986). Some biologists are asking whether higher priority shouldn't be given to preserving "evolutionary fronts" of ongoing diversification. Bruford, *supra* note 148, at 4.

[562] Michael McKinney refers to such types of organism as "evolutionary supertaxa," and suggests that they tend to be "broadly adapted abundant species" that are "widespread and have high rates of population growth." McKinney, *supra* note 242, at 10. *See also supra* notes 409-414 and accompanying text.

[563] Kaneko & Yomo, *supra* note 158, at 345-46. For example, a study of Hawaiian spiders found that if immigration to a particular island did not fill a particular niche that was available for spiders, sympatric speciation of the island's existing spiders tended to fill the niche. Rosemary Gillespie, *Community Assembly Through Adaptive Radiation in Hawaiian Spiders*, 303 SCI. 356

accumulating that this kind of "sympatric" speciation may have been the origin of many species groups.[564] Much of this research has been stimulated by investigation into the wide variety of *cichlid* fish species found in the lakes of the African rift valley.[565] This research suggests that each species evolved by occupying a unique niche in the lake environment.[566]

Paleoecological analysis suggests that over evolutionary time scales there have been roughly equal rates of speciation and extinction, except during the few periods of mass extinction,[567] but that increased human occupation of natural areas is likely to increase extinction rates and decrease speciation rates.[568] However, invasions of species often encourage allopatric speciation if the invasive species becomes isolated and adapts to new environmental conditions,[569] or if native species are unable to disperse effectively and individual populations begin to speciate allopatrically.[570] Moreover, entire native species can sometimes

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(2004). *See generally* ENDLESS FORMS: SPECIES AND SPECIATION 79-216 (Daniel J. Howard & Stewart H. Berlocher eds., 1998).

[564] Michael Doebeli & Ulf Dieckmann, *Evolutionary Branching and Sympatric Speciation Caused by Different Types of Ecological Interactions*, 156 AM. NATURALIST S77, S93 (2000) [hereinafter *Evolutionary Branching*]; Ulf Dieckmann & Michael Doebeli, *On the Origin of Species by Sympatric Speciation*, 400 NATURE 354 (1999); Kerstin Johannesson, *Parallel Speciation: A Key to Sympatric Divergence*, 16 TRENDS IN ECOLOGY AND EVOLUTION 148 (2001) (citing repeated and independent examples of speciation by the same mechanism and in the absence of extrinsic barriers).

[565] HERBERT R. AXELROD & WARREN E. BURGESS, AFRICAN CICHLIDS OF LAKES MALAWI AND TANGANYIKA 250 (11th ed. 1989). *See also* AVISE, *supra* note 85, at 146-49.

[566] *See* GEORGE W. BARLOW, THE CICHLID FISHES: NATURE'S GRAND EXPERIMENT IN EVOLUTION (2000); DAVID QUAMMEN, THE SONG OF THE DODO: ISLAND BIOGEOGRAPHY IN AN AGE OF EXTINCTIONS 232-34 (1990); Doebeli & Dieckmann, *Evolutionary Branching*, *supra* note 564, at S93; Erik Verheyen et al., *Origin of the Superflock of Cichlid Fishes from Lake Victoria, East Africa*, 300 SCI. 325, 325 (2003). *But see* Irv Kornfield & Peter F. Smith, *African Cichlid Fishes: Model Systems for Evolutionary Biology*, 31 ANN. REV. OF ECOLOGY & SYSTEMATICS 163, 184 (2000) ("We caution against premature adoption of particular divergence scenarios in the absence of sufficiently strong evidence.").

[567] *See* LIEBERMAN, *supra* note 560, at 179.

[568] Rosenzweig, *supra* note 450.

[569] *See* discussion at notes 272-275 *supra*.

[570] Nathan, *supra* note 532, at 149. Rapid evolution can also take place among populations of species that are confined in artificial habitats. Carl Zimmer, *Rapid Evolution Can Foil Even the Best-Laid Plans*, 300 SCI. 895 (2003) (farmed salmon quickly begin to lay smaller eggs that thrive in the

evolve rapidly in response to threats posed by invasive species.[571]

Recent research in evolutionary biology leads some scientists to believe that many organisms have the ability to increase their rate of mutations when they sense rapid environmental change.[572] In particular, insects, bacteria, and other organisms have developed resistance to antibiotics, pesticides, and herbicides with troubling rapidity.[573] As the National Research Council has observed, "[b]ecause of their rapid growth rate and large populations, microbes can evolve very quickly, allowing them to adapt to new hosts, produce new toxins, and bypass immune responses."[574] Microbial resistance to antibiotics is a growing and understudied problem in managing disease.[575] The processes by which resistance develops outside the laboratory are still poorly understood,[576] but the fact that resistance is occurring nonetheless highlights the underlying question of whether speciation arising from these anthropogenic causes should be considered as contributing to biodiversity.

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controlled environment of the hatchery but would be less likely to survive in the wild).

571 Mooney & Cleland, *supra* note 387, at 5447. *See also* Palumbi, *supra* note 559, at 28-29 (house sparrows have evolved into distinct varieties since their introduction in 1851). Mark Williamson cautions, however, that most evolution is still slow in comparison to the process of invasion. WILLIAMSON, *supra* note 388, at 172-73.

572 *See, e.g.*, Thaler, *supra* note 66, at 224; Chicurel, *supra* note 66.

573 *See, e.g.*, MERRELL, *supra* note 53, at 43-46; Given et al., *supra* note 232, at 11.

574 NAT'L RESEARCH COUNCIL, *supra* note 55, at 39.

575 *Id*. at 41.

576 Mark D. Rausher, *Co-Evolution and Plant Resistance to Natural Enemies*, 411 NATURE 857 (2001). Scientists are beginning to develop strategies to slow the evolution of resistance to antibiotics, but progress is slow. Stephen R. Palumbi, *Humans as the World's Greatest Evolutionary Force*, 293 SCI. 1786, 1788-89 (2001) (development of strategies to slow evolution of resistance).

## PUZZLE #11: SHOULD WE ENCOURAGE ALL INCREASES IN BIODIVERSITY THAT RESULT FROM NATURAL SELECTION, EVEN THOUGH THIS MAY INCLUDE SPECIES THAT ARE RESISTANT TO ANTIBIOTICS OR PESTICIDES, OR SHOULD WE ONLY EMPHASIZE PROTECTION OF THE BIODIVERSITY OF EXISTING SPECIES?

b. *Engineering biodiversity?*

In his study of evolution, Darwin paid particular attention to the activities of plant and animal breeders, who had been modifying the form of organisms for centuries.[577] The captive breeding of animals to be released into the wild has been a common practice for many decades.[578] In particular, species in demand for sport or commercial hunting and fishing have been released in order to increase fish and game stocks.[579] Recently, this practice has become more controversial because of its potentially adverse impact on biodiversity.[580] For example, introduced rainbow trout have swamped many local species of trout genetically,[581] and a serious disease affecting native deer populations in many parts of the United States has been traced to animals bred in captivity for release into the wild.[582] Hatchery-raised fish, which were once thought to be a significant contribution to the natural environment, are now often seen as

[577] CHARLES DARWIN, 1 THE VARIATION OF ANIMALS AND PLANTS UNDER DOMESTICATION 446-47 (1868). Darwin noted:

> Some writers, who have not attended to natural history, have attempted to show that the force of inheritance has been much exaggerated. The breeders of animals would smile at such simplicity; and if they condescended to make any answer, might ask what would be the chance of winning a prize if two inferior animals were paired together.

*Id*. *See also* PETER J. BOWLER, EVOLUTION: THE HISTORY OF AN IDEA 166 (3d ed., 2003).

[578] THOMAS A. LUND, AMERICAN WILDLIFE LAW 67-68 (1980).

[579] *Id*. at 68-70.

[580] *See, e.g.*, N. F. R. Snyder et al., *Limitation of Captive Breeding in Endangered Species Recovery*, 10 CONSERVATION BIOLOGY 338 (1996).

[581] Peter Jenkins, *Harmful Exotics in the United States*, *in* BIODIVERSITY AND THE LAW 105, 106 (William J. Snape ed., 1996).

[582] NAT'L WILDLIFE HEALTH CTR., CHRONIC WASTING DISEASE, *at* http://www.nwhc.usgs.gov/research/chronic_wasting/chronic_wasting.html (last modified Feb. 25, 2004).

threats to the native populations of the same species.[583] Fish raised in hatcheries can harm wild populations by introducing maladaptive genes.[584] This led NMFS to treat captive-bred fish as distinct from natural populations of their species for purposes of listing the species as threatened or endangered under the ESA.[585] After a federal district court held that such a distinction was not authorized by the statute,[586] the Commerce Department chose not to appeal and began a revaluation of its policy relating to hatchery-raised Pacific salmon.[587]

More recently, networks of zoos have developed captive breeding programs as a way of creating "species survival plans" for rare species[588] or to increase their genetic variability.[589] Black-footed ferrets, for example, had been reduced to captive breeding populations, and the red wolf existed only in captive breeding facilities and on three islands known to be too small to harbor a wild population for any length of time.[590]

Humans are also the proximate cause of another kind of speciation. Where humans have caused species to be split up into isolated populations, allopatric speciation may take place over time.[591] So, for example, if urban development in the middle of the range of a particular species separates the individuals into

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583 Ruckleshaus et al., *supra* note 116, at 682. *See also* Tracy Dobson et al., *supra* note 344, at 403-10 (hatcheries in the Great Lakes were ineffectual until they began to rear threatened native species).

584 NOSS & COOPERRIDER, *supra* note 112, at 284-86.

585 Ruckleshaus et al., *supra* note 116, at 670.

586 Alsea Valley Alliance v. Evans, 161 F. Supp. 2d 1154, 1161 (D. Or. 2001), *appeals dismissed*, 358 F.3d 1181 (9th Cir. 2004). Counsel for the plaintiffs discuss the case in Leslie Marshall Lewallen & Russell C. Brooks, Alsea Valley Alliance v. Evans *and the Meaning of "Species" under the Endangered Species Act: A Return to Congressional Intent*, 25 SEATTLE UNIV. L. R. 731, 733-34 (2002).

587 Endangered and Threatened Species: Findings on Petitions to Delist Pacific Salmonid ESUs, 67 Fed. Reg. 6215, 6216 (Feb. 11, 2002).

588 TONGREN, *supra* note 59, at 42-56. The debates over whether captive breeding has been given too high a priority in conservation efforts are discussed in Bruford, *supra* note 148, at 13-18. *See also* CONSERVATION OF ENDANGERED SPECIES IN CAPTIVITY: AN INTERDISCIPLINARY APPROACH (EDWARD F. GIBBONS, JR. ET AL. EDS., 1995).

589 *See, e.g.*, DIV. OF ENDANGERED SPECIES, *supra* note 114; Judith Kolbas, *The Mongolian Wild Horse*, 47 FOCUS 26, 27 (Fall 2002). *See generally* TONGREN, *supra* note 59.

590 Doremus, *supra* note 14, at 38-39.

591 *See supra* note 560 and accompanying text.

disconnected populations, which over time develop characteristics that prevent interbreeding, should each population be characterized as a separate species?[592] Are these human-created species in the same way as those created by captive breeding? If so, should we assign them a lesser priority?[593]

Today, science has carried captive breeding to another level. Molecular biologists have developed methods of creating new kinds of plants and animals through biotechnological techniques for manipulating genes and moving them from one organism to a very different organism.[594] For example, biogeneticists have learned to create plants with enhanced resistance to herbicides.[595] Biotechnology speeds up the process of speciation that otherwise takes place quite slowly through natural selection; as Edward Wilson puts it, "genetic evolution is about to become conscious and volitional, and usher in a new epoch in the history of life."[596]

Some conservation biologists believe that genetic engineering will eventually be helpful in reducing some local extinctions caused by exotic pests and diseases.[597] They believe that the

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[592] For an example of some of the confusion regarding the legal status of populations in such situations under the ESA, see generally Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the Coastal California Gnatcatcher (*Polioptila Californica Californica)* and Determination of Distinct Vertebrate Population Segment for the California Gnatcatcher (*Polioptila californica*); Proposed Rule, 68 Fed. Reg. 20,228 (April 24, 2003).

[593] Bruford, *supra* note 148, at 11-13 (discussing need for more research into inbreeding and genetic drift among anthropogenically isolated populations).

[594] *See* Colwell, *supra* note 74, at 280. *See also* BRIGHT, *supra* note 414, at 59.

[595] In the year 2000, seventy percent of the commercially planted transgenic varieties had herbicide resistance and twenty-eight percent carried insecticide resistance. HAROLD BROOKFIELD, EXPLORING AGRODIVERSITY 251-52 (2001). *See also* WILLIAMSON, *supra* note 388, at 173-76. On the question of whether herbicide-tolerant crops may benefit biodiversity because spraying of crops may be delayed until later in the growing season, allowing weeds to provide an enhanced resource for arthropods and the birds that feed on them, see R. P. Freckleton et al., *Amelioration of Biodiversity Impacts of Genetically Modified Crops: Predicting Transient versus Long-term Effects*, 271 PROCEEDINGS OF THE ROYAL SOCIETY, LONDON, Series B 325 (2003) (finding that observed positive effects on biodiversity are likely to be transient).

[596] WILSON, *supra* note 133, at 270. *See also* Woodruff, *supra* note 101, at 5474 ("[T]he interventionist genetic and ecological management of species, communities, and ecosystems in a postnatural world, is poised to become a growth industry.").

[597] Jonathan M. Adams et al., *The Case for Genetic Engineering of Native and Landscape Trees Against Introduced Pests and Diseases*, 16 CONSERVATION BIOLOGY 874, 878 (2002). It has been suggested that some conservationists

introduction of genetically modified organisms will pose no more risks than the introduction of any other new species.[598]

On the other hand, other biologists are concerned that the increased resistance of biotechnologically-created species may enable them to out compete those without such resistance, with resulting extinction risks.[599] Other scientists worry that, because the target of genetic manipulation is usually a single cell, the modified organisms will all derive their genes from that cell, which means they will have limited genetic diversity and thus be very susceptible to an epidemic or disaster.[600] Still other concerns involve the impact of pest-resistant features of new species on organisms that are not thought of as pests.[601]

Should biodiversity policy treat species created by biotechnology the same as species that originated by other means?[602] The issues posed by bioengineering range far beyond

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support genetically modified crops because they will produce more food on existing agricultural land, thereby allowing us to devote more land to biodiversity preservation. Vandermeer, *supra* note 529, at 60.

598 Brian A. Barlow & George T. Tzotzos, *Biotechnology*, *in* GLOBAL BIODIVERSITY ASSESSMENT 671, 701 (V. H. Heywood ed., 1995) (introduction of transgenic animals should be treated like the release of any other exotic species).

599 *See, e.g.*, Erik Stokstad, *Engineered Fish: Friend or Foe of the Environment?*, 297 SCI. 1797 (2002). Both sides of this argument are set out in John Charles Kunich, *Mother Frankenstein, Doctor Nature, and the Environmental Law of Genetic Engineering*, 74 SO. CAL. L. REV. 807 (2001). *See also generally* H. D. COOPER ET AL. EDS., BROADENING THE GENETIC BASE OF CROP PRODUCTION (2002) (arguing that domestication, migration, and breeding have caused low genetic variability in many crops, which can lead to increased crop vulnerability).

600 Vida, *supra* note 55, at 14.

601 Media attention has focused on the potential impact of genetically altered corn on the Monarch butterfly, but a series of studies seems to suggest that such impact will be minimal, though there may be a greater impact on other butterfly species. *See* A. R. Zangeri et al., *Effects of Exposure to Event 176 Bacillus Thuringiensis Corn Pollen on Monarch and Black Swallowtail Caterpillars Under Field Conditions*, 98 PROC. NAT'L ACAD. SCI. 11,908, 11,908 (2001). Other related reports are found in the same volume. Whatever impact the resistant corn may have on non-pest species needs to be evaluated against the benefits to such species that will come from the reduced need to spray pesticides on the corn. David S. Pimentel & Peter H. Raven, *Bt Corn Pollen Impacts on Nontarget Lepidoptera: Assessment of Effects in Nature*, 97 PROC. NAT'L ACAD. SCI. 8198 (2000). *See also* MARK L. WINSTON, TRAVELS IN THE GENETICALLY MODIFIED ZONE 84-93 (2002).

602 The "fundamental question" is whether genetically modified organisms "are simply another in a long line of advances in agricultural technology" or whether "they represent a 'new species of trouble.'" John S. Applegate & Alfred C. Aman, Jr., *Syncopated Sustainable Development*, 9 IND. J. GLOBAL LEGAL

the bounds of biodiversity policy. Are the risks associated with genetic engineering so great that government should be approaching the regulation of this field more cautiously than it now does?[603] Or does irrational fear of this technology lead to increased health risk from the use of pesticides on unmodified crops?[604] What role should the notion of biodiversity play in these debates?

## PUZZLE #12:
## SHOULD WE PROTECT GROUPS OF ORGANISMS THAT RESULT FROM CAPTIVE BREEDING OR BIOENGINEERING IN THE SAME WAY THAT WE PROTECT GROUPS OF "NATURAL" ORIGIN?

### 3. *CAN LOSS OF BIODIVERSITY BE ADAPTIVE?*

Evolution "generates, sustains, shapes, and *sometimes even diminishes* biodiversity."[605] Is loss of local biodiversity sometimes essential to allow organisms to adapt to changing conditions? Wildlife Conservation Society marine biologist Andrew Baker has put forward a hypothesis that suggests that one of the most dreaded examples of loss of biodiversity–the bleaching of coral reefs–may be a necessary process by which coral adapts to increasing water temperature.[606] His example, which is analogous to other potential adaptations to climate change, provides a reason to list a thirteenth puzzle, thus creating a Baker's dozen.

Most coral species are naturally white.[607] The brilliant colors

STUD. 1, 10 (2002) (quoting KAI ERICKSON, A NEW SPECIES OF TROUBLE: EXPLORATIONS IN DISASTER, TRAUMA AND COMMUNITY (1994)).

[603] This issue has been widely debated in recent years, and the details of the debate would unduly enlarge the scope of this paper. *Compare* Sophia Kolehmainen, *In Depth: Genetically Engineered Agriculture: Precaution Before Profits: An Overview of Issues in Genetically Engineered Food and Crops*, 20 VA. ENVTL. L. J. 267 (2001) *with* Stanley H. Abramson & J. Thomas Carrato, *Crop Biotechnology: The Case for Product Stewardship*, 20 VA. ENVTL. L. J. 241 (2001).

[604] David Pimentel, *Overview of the Use of Genetically Modified Organisms and Pesticides in Agriculture*, 9 IND. JOURNAL OF GLOBAL LEGAL STUD. 51, 58-60 (2002); Drew L. Kershen, *Agricultural Biotechnology: Environmental Benefits for Identifiable Environmental Problems*, 32 ENVTL. L. REP. 11,312 (2002).

[605] NAT'L RESEARCH COUNCIL, *supra* note 19, at 21 (emphasis added).

[606] Andrew C. Baker, *Reef Corals Bleach to Survive Change*, 411 NATURE 765 (2001).

[607] John D. Hedley & Peter J. Mumby, *Biological and Remote Sensing*

that we see are provided by a remarkably complex, and poorly understood, array of algae and other microorganisms.[608] During the late 1990s, coral reefs throughout the world experienced episodes of "bleaching" in which the microorganisms disappeared, leaving only the white coral skeletons.[609] The bleaching has generally been attributed to increased water temperatures,[610] and some commentators have suggested that the bleaching events could serve as an indicator of the dangerous effects of climate change.[611]

Baker ran experiments in which he transferred corals between differing depths of water, causing them to become exposed to differing levels of sunlight.[612] He found that corals that were raised closer to the surface (and thus closer to brighter light) tended to bleach, but that the bleached coral subsequently attracted new kinds of algae that were adapted to higher light levels.[613]

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*Perspectives of Pigmentation in Coral Reef Organisms*, 43 ADVANCES IN MARINE BIOLOGY 277, 290-92 (2002).

[608] MARK D. SPALDING ET AL., WORLD ATLAS OF CORAL REEFS 35 (2001). *See also* Todd G. LaJeunesse, *Investigating the Biodiversity, Ecology, and Phylogeny of Endosymbiotic Dinoflagellates in the Genus Symbiodinium Using the ITS Region: In Search of a "Species" Level Marker*, 37 J. OF PHYCOL. 866 (2001); Xavier Pochon et al., *High Genetic Diversity and Relative Specificity among Symbiodinium-like Endosymbiotic Dinoflagellates in Soritid Foraminiferans*, 139 MARINE BIOLOGY 1069 (2001). *See generally* Tim R. McClanahan et al., *The Resilience of Coral Reefs*, *in* RESILIENCE AND THE BEHAVIOR OF LARGE-SCALE SYSTEMS 111 (Lance H. Gunderson & Lowell Pritchard Jr. eds., 2002).

[609] Tundi Agardy, *America's Coral Reefs: Awash with Problems*, 20 ISSUES IN SCI. AND TECH. 35, 37 (2004). *See also* Ove Hoegh-Guldberg, *Climate Change, Coral Bleaching and the Future of the World's Coral Reefs*, 50 MARINE & FRESHWATER RESEARCH 839 (1999).

[610] SPALDING ET AL., *supra* note 608, at 59-61. *See, e.g.*, ROSALEEN LOVE, REEFSCAPE: REFLECTIONS ON THE GREAT BARRIER REEF 175-81 (2001). For an interesting discussion of the concern about coral reefs by a science historian, see JAN SAPP, WHAT IS NATURAL?: CORAL REEF CRISIS (1999). *See also* Callum M. Roberts et al., *Marine Biodiversity Hotspots and Conservation Priorities for Tropical Reefs*, 295 SCI. 1280 (2002).

[611] Timothy R. McClanahan, *The Near Future of Coral Reefs*, 29 ENVTL. CONSERVATION 460 (2002); Brian C. O'Neill & Michael Oppenheimer, *Dangerous Climate Impacts and the Kyoto Protocol*, 296 SCI. 1971 (2002). It should be noted that in addition to any impact of climate change, coral reefs in some regions have been under pressure from a wide range of pathogens and a wide range of human activities for decades. *See, e.g.*, Toby A. Gardner et al., *Long-Term Region-Wide Declines in Caribbean Corals*, 301 SCI. 958, 960 (2003).

[612] Baker, *supra* note 606, at 765.

[613] *Id*. at 765-66.

Baker argues that the fact that these corals survived well is evidence in support of a hypothesis that bleaching is the coral's way of expelling algae that are no longer adapted to the environment in order to attract new algae that are better adapted.[614]

Today humans are causing incremental changes in the environment that are one-directional and do not replicate cyclical patterns in nature.[615] The increasing concentrations of greenhouse gases and urbanized land use are only the most conspicuous of many examples.[616] University of Arizona ecologist Michael Rosenzweig argues that the decline in biodiversity is inevitable in the long run because the number of species is proportional to the size of natural areas, and that size seems to be decreasing inexorably.[617] Ecologists fear that many species will have great

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[614] *Id*. Bleaching is an extreme version of a symbiont regulatory mechanism in which algal densities change in response to a changing environment over seasonal and shorter timescales. Andrew C. Baker, *Flexibility and Specificity in Coral-Algal Symbiosis: Diversity, Ecology, and Biogeography of* Symbiodinium, 34 ANN. REV. OF ECOLOGY, EVOLUTION AND SYSTEMATICS 661, 678-81 (2003). Corals "usually recover from bleaching but they can die in extreme cases." SPALDING ET AL., *supra* note 608, at 59; B. E. Brown et al., *Exploring the Basis of Thermotolerance in the Reef Coral Goniastrea Aspera*, 242 MARINE ECOLOGY: PROGRESS SERIES 119 (2002) (corals which acclimate to high irradiance can develop tolerance to higher water temperatures and resist bleaching). The sensitivity of corals to changes in the amount of light they receive is well known, and in some cases corals appear to be suffering from lowered light levels caused by increased sedimentation or eutrophication. C. S. Yentsch et al., *Sunlight and Water Transparency: Cornerstones in Coral Research*, 268 J. OF EXPERIMENTAL MARINE BIOLOGY AND ECOLOGY 171, 180 (2002). For a critique of Baker's article and Baker's response, see Ove Hoegh-Guldberg et al., *Is Coral Bleaching Really Adaptive?*, 415 NATURE 601 (2002). *See also* T.P Hughes et al., *Climate Change, Human Impacts, and the Resilience of Coral Reefs*, 301 SCI. 929, 930 (2003) (suggesting that a change in algae after bleaching does not necessarily indicate that any evolutionary response has occurred); McClanahan, *supra* note 611, at 472 ("[E]vidence to support the adaptive bleaching hypothesis is still largely circumstantial . . . .").

[615] For example, destructive changes to some Western grasslands caused by climate change and overgrazing may already have crossed a threshold to a new ecological state that could not easily be reversed even if grazing were ended. DONAHUE, *supra* note 387, at 145-46; Joseph M. Feller & David E. Brown, *From Old-Growth Forests to Old-Growth Grasslands: Managing Rangelands for Structure and Function*, 42 ARIZ. L. REV. 319, 321 (2000); MCPHERSON & DESTEFANO, *supra* note 408, at 46.

[616] *See* Bosselman, *supra* note 13, at 274-94.

[617] Michael L. Rosenzweig, *The Four Questions: What Does the Introduction of Exotic Species Do to Diversity?*, 3 EVOLUTIONARY ECOLOGY RES. 361, 366 (2001). *See also* ROSENZWEIG, *supra* note 552, at 101-26.

difficulty in adapting to this rate of natural area loss,[618] and that the resulting loss of biodiversity will make it more difficult to maintain ecological processes capable of coping with these trends of environmental change.[619]

Is Baker's hypothesis applicable in a wide range of other contexts? With the increasing air temperatures of the past twenty-five years,[620] similar cases have been widely noted in which both terrestrial and marine organisms are reacting to increased temperature by various mechanisms,[621] including changes in the flowering times of plants,[622] the egg-laying times of birds,[623] and the altered performance of insect herbivores.[624] Species that reproduce rapidly can often adapt to environmental change by evolving through natural selection of the traits best suited to the new environmental conditions.[625] Other animals and some relatively mobile plant species have extended their range northward or upwards, leaving behind areas to which they are now poorly adapted.[626] Some data suggests that birds in habitats that

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[618] Macdonald & Johnson, *supra* note 437, at 366 (climate change is requiring many plants to disperse perhaps ten times faster than in the last ice age retreat).

[619] Sandy L. Tartowski, et al., Integration of Species and Ecosystem Approaches to Conservation, *in* THE ECOLOGICAL BASIS OF CONSERVATION: HETEROGENEITY, ECOSYSTEMS, AND BIODIVERSITY 187, 190 (S.T.A. Pickett et al. eds., 1997) ("Perhaps the most critical environmental impact of decreased biodiversity will be decreased resistance and resilience in response to environmental variance.").

[620] For a review of studies of macroecological impacts of climate fluctuations, see Nils C. Stenseth et al., *Ecological Effects of Climate Fluctuations*, 297 SCI. 1292 (2002).

[621] *See generally* STEPHEN H. SCHNEIDER & TERRY L. ROOT, WILDLIFE RESPONSES TO CLIMATE CHANGE: NORTH AMERICAN CASE STUDIES (2002) (discussing numerous North American examples); Brian Helmuth et al., *Climate Change and Latitudinal Patterns of Intertidal Thermal Stress*, 298 SCI. 1015 (2002). *See also* Bosselman, *supra* note 13, at 279-82 nn. 468-91.

[622] A. H. Fitter & R. S. R. Fitter, *Rapid Changes in Flowering Time in British Plants*, 296 SCI. 1689 (2002) (documenting that average flowering time of 385 British plant species advanced by 4.5 days during the past decade).

[623] Merilä et al., *supra* note 68, at 76.

[624] J. H. Lawton, *Biodiversity, Ecosystem Processes, and Climate Change*, *in* ECOLOGY: ACHIEVEMENT AND CHALLENGE 139, 146 (Malcolm C. Press et al. eds., 2001).

[625] Peter R. Grant & B. Rosemary Grant, *Unpredictable Evolution in a 30-Year Study of Darwin's Finches*, 296 SCI. 707 (2002) (illustrating that natural selection operates over short time periods).

[626] *See, e.g.*, J. Alan Pounds et al., *Biological Response to Climate Change on a Tropical Mountain*, 398 NATURE 611, 611 (1999); Josep Peñuelas and Iolanda Filella, *Responses to a Warming World*, 294 SCI. 793 (2001). On the other hand,

are experiencing warming trends may be experiencing the most rapid population declines; this might indicate that they have dispersed northward in response to the higher temperatures.[627] Although this may reduce local biodiversity at any given time and place, such adaptations may be necessary to the long-run survival of the species.[628]

Where local biodiversity declines as a result of climate change, should we try to restore the former diversity in the hope that the climate change can be reversed? Or should we look at the reduction of diversity as the creation of new ecological niches that may become filled by species that are more adaptable to future conditions?

## PUZZLE #13 ("BAKER'S PUZZLE")
## SHOULD WE TRY TO MAINTAIN EXISTING BIODIVERSITY OR TO PROMOTE NEW MIXTURES OF SPECIES THAT CAN BETTER ADAPT TO CONTINUING ENVIRONMENTAL CHANGE?

In summary, biodiversity is a complex and sometimes conflicting puzzle, full of ideas of great importance.[629] In this connection, it is important to distinguish between a definition of biodiversity as a field of study and a definition of biodiversity that creates a legal obligation.[630] Proponents of biodiversity probably have the immediate reaction that any definition of the topic should be as broad and inclusive as possible, and this is fine when the definition is used to establish the boundaries of the field. However, if we wish to create legal obligations to protect biodiversity, then the broader and more inclusive the definition

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species such as the Marbled Murrelet, which have a low reproductive rate and depend on habitats that take centuries to grow, may be the most threatened by climate change. Beissinger et al., *supra* note 271, at 563.

[627] *See* Francis C. James et al., *New Approaches to the Analysis of Population Trends in Land Birds*, 77 ECOLOGY 13, 19 (1996).

[628] *See* GASTON, *supra* note 274, at 186 ("In any given region, some species will become extinct, some that were rare will become more abundant and widespread, some that were abundant will become scarce and restricted, and yet others will colonize from elsewhere."). *See also* NAT'L RESEARCH COUNCIL, *supra* note 19, at 22 (suggesting that evolution sometimes even diminishes biodiversity); J. H. Lawton, *supra* note 624, at 144-46 (stating that replacement can take place only if there is a pool of new species available).

[629] *See supra* Parts II.A-II.C.

[630] *Compare supra* notes 29-33 and accompanying text (discussing biodiversity used as a legal standard) *with supra* Part II.

becomes, the more likely it is to present administrators with irreconcilable conflicts that will lead to unproductive litigation. If we are going to successfully employ some version of biodiversity as a workable legal standard, we need to expend more effort trying to "unbundle" the various components of biodiversity to see what we really intend the concept to mean in any given application.

## III
## LIVING WITH PUZZLES

What can the law[631] do about these scientific puzzles? No clever judge, ingenuous scrivener, brilliant legislator, or masterful administrator—nor even the most sagacious law professor—can work these scientific puzzles like the daily crossword and say "that's solved." The combined resources of the world's scientific research establishment will undoubtedly continue to make progress toward some solutions, but they will probably be creating new puzzles in the process. So what can the law contribute?

From past experience, we can expect that when the law faces an unsolved scientific puzzle, it typically chooses from a variety of strategies it has used before: (1) it can simply *postpone* the puzzle by pretending that it doesn't exist;[632] (2) the law can *override* the scientific puzzle by taking the position that non-scientific values require a certain result whether or not science agrees;[633] (3) the law can *choose* sides, accepting the view of one group of scientists and rejecting others;[634] (4) often the law uses *triage*, deciding not to expend the resources needed to address an acknowledged scientific puzzle because it believes that such an expenditure of resources lacks sufficient priority among all potential expenditures;[635] or (5) the law may use *adaptive management*, creating a process by which the scientific puzzle can be addressed and the conclusion fed back into the legal process.[636]

Each of these approaches may be appropriate for one or more

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[631] I use the term "the law" in this section to include all elements of American lawmaking, including executive, legislative, and judicial branches of government.

[632] *Infra* Part III.A.

[633] *Infra* Part III.B.

[634] *Infra* Part III.C.

[635] *Infra* Part III.D.

[636] *Infra* Part III.E.

of the puzzles discussed herein, and for others that will surely arise. This Part will offer some very tentative suggestions for the way that the law might approach the puzzles previously discussed,[637] but it should be recognized that ongoing scientific research may make these recommendations quickly obsolete.

### A. *Postponement*

Our legal system has a history of ignoring some scientific puzzles because potential impacts are thought to be too far in the future—although the decision whether or not to postpone an issue is often puzzling in and of itself. Consider, for example, the potential impact of an asteroid striking earth. This has been projected as a possibility in the year 2880,[638] less than nine centuries from now, but the issue has yet to make it to the top of any legislative agenda.[639] It may seem premature to plan eight hundred years ahead, but we have, on the other hand, decided to expend substantial resources on attempts to predict the future behavior of radioactive material to be stored at Yucca Flat for more than nine *millennia* in the future.[640]

So the extent to which we are willing to postpone scientific issues involves differing attitudes toward risk perception that are far beyond my comprehension.[641] The most notable current example is that the fact that the U.S. government appears to believe that there is so little likelihood that emission of greenhouse

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[637] *Supra* Part II.

[638] It has been estimated that asteroid 1950 DA has a 0.3% possibility of hitting the earth on March 16, 2880. Steven Ward & Erik Asphaug, *Asteroid Impact Tsunami of 2880 March 16*, 153 GEOPHYS. J. INT. F6, F6 (2003). Modelers have predicted that if 1950 DA landed in the Atlantic Ocean, it could create tsunami waves more than 100 meters high. *Id*. at F8.

[639] *See generally* Andrea Milani, *Extraterrestrial Material–Virtual or Real Hazards*, 300 SCI. 1882, 1883 (2003). For an argument that it should make it to the top of the legislative agenda, see Evan R. Seamone, *The Duty to Expect the Unexpected: Mitigating Extreme Natural Threats to the Global Commons Such as Asteroid and Comet Impacts with the Earth*, 41 COLUM. J. TRANSNAT'L L. 735 (2003).

[640] *See* Kai Erickson, *12,0001 A.D.: Are You Listening? Out of Sight, Out of Mind*, THE N.Y. TIMES MAGAZINE, March 6, 1994, at 34.

[641] For a careful study of the various ways of "spinning" risk information, see NAT'L RESEARCH COUNCIL, IMPROVING RISK COMMUNICATION 94-142 (1989) (addressing common misperceptions regarding risk communication and problems of risk communication arising from political and other institutionalized systems, communicators themselves, and recipients of communications).

gases will cause a steady increase in global warming over the next century that it is not even mentioned in the EPA's state of the environment report,[642] despite the fact that there is no sign of a halt in the steady warming trend that has prevailed for the past three decades.[643]

I would not advocate this "head in the sand" attitude toward many of the puzzles discussed in this Article. We might, however, legitimately postpone one of the puzzles discussed in this Article until it becomes more imminent. The legal issues posed by a class of bioengineered organisms that threatens to go extinct[644] could be left for another day. The creation of new organisms through bioengineering is with us, like it or not,[645] and it is beyond the scope of this Article to discuss the nature and extent of the controls

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[642] *See* Andrew C. Revkin & Katherine Q. Seelye, *Report by E.P.A. Leaves Out Data on Climate Change*, N.Y. TIMES, June 19, 2003, at A1; Elizabeth Shogren, *Editing Flap Over EPA's Report on Environment; Whitman Cut Section on Climate Because Only Language White House Agreed on Was 'Pablum*,' L.A. TIMES, June 20, 2003, at A16 ("'It didn't have the depth and credibility that the rest of the report has,' Whitman said. 'If all you can get is pablum, it is better not to do anything.'"). For the critical viewpoint of a former EPA official, see Jeremy Symons, *How Bush and Co. Obscure the Science*, THE WASHINGTON POST, July 13, 2003, at B4. For a summary of the Bush administration's attempts to suppress climate change information, see the report on "Politics & Science" by the minority staff of the House Committee on Government Reform. Rep. Henry Waxman, *Politics & Science: Investigating the State of Science under the Bush Administration, The Science of Global Warming*, *at* http://www.house.gov/reform/min/politicsandscience/example_global_warming.htm (last visited Jan. 19, 2004).

[643] *See* NAT'L CLIMACTIC DATA CNTR., NAT'L OCEANIC AND ATMOSPHERIC ADMIN., CLIMATE OF 2002 ANNUAL REVIEW (Jan. 23., 2003), *at http://www.ncdc.noaa.gov/oa/climate/research/2002/ann/ann02.html*. According to the review:

> Global temperatures in 2002 were 0.56°C (1.01°F) above the long-term (1880-2001) average, which places 2002 as the second warmest year on record. The only warmer year was 1998 in which a strong El Niño contributed to higher global temperatures. Land temperatures were 0.87°C (1.57°F) above average and ocean temperatures 0.42°C (0.76°F) above the 1880-2001 mean.

*Id*. (notations omitted). A more recent NCDC report found that 2003 tied 2002 for the second-warmest year on record. The report is available *at* ftp.ncdc.noaa.gov/pub/data/anomalies/annual_land.and.ocean.ts.

[644] *See supra* notes 602-604.

[645] *See, e.g.*, Charles C. Mann & Mark L. Plummer, *Forest Biotech Edges Out of the Lab*, 295 SCI. 1626 (2002) (discussing environmental risks and potential benefits of bioengineered trees).

that can or should be imposed on the creation of new species.[646] However, we must eventually consider the extent to which human-created "species" are due the same protection that we give to other components of biodiversity. I can see no rational argument why we should not give them the same protection, but perhaps the fact that we have learned how to create these species suggests that there will not be many situations in which they become so endangered that we cannot re-create them. In the end, the policy issue will probably depend more on the outcome of philosophical debates over attitudes toward nature than on any attempt to construct a scientific definition of biodiversity that includes or excludes genetically modified organisms.[647] Of the puzzles discussed in the Article, that is the only one I would be comfortable postponing.

### B. *Override*

The law often overrides scientific puzzles by basing policy decisions on other kinds of values. The former head of the Office of Technology Assessment says that his agency was often reminded of Victor Hugo's admonition: "Science says the first word on everything, but the last word on nothing."[648]

A recent example is the President's decision to limit stem cell research.[649] In the debates over this issue, the proponents argued that stem cells from human embryos were uniquely valuable for medical research, while opponents argued that there were ethical and religious objections to the use of embryos for this purpose.[650]

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[646] My colleague Sheldon Nahmod has posed an interesting legal issue: to what extent would restrictions on the development of transgenic species survive First Amendment analysis? Sheldon Nahmod, *The GFP (Green) Bunny: Reflections on the Intersection of Art, Science, and the First Amendment*, 34 SUFFOLK U. L. REV. 473, 479-81 (2001).

[647] *See* Mark Sagoff, *Biotechnology and Agriculture: The Common Wisdom and Its Critics*, 9 IND. J. OF GLOBAL LEGAL STUD. 13, 28-32 (2002) (discussing the "ecological critique of agricultural biotechnology" and differing notions of the meanings of "nature").

[648] JOHN H. GIBBONS, THIS GIFTED AGE: SCIENCE AND TECHNOLOGY AT THE MILLENNIUM xiii (1997).

[649] *See* Katharine Q. Seelye, *The President's Decision: the Overview; Bush Gives His Backing for Limited Research on Existing Stem Cells*, N.Y. TIMES, Aug. 10, 2001, at A1. The United States is not alone in debating this issue. *See* Peter Gruss, *Human ES Cells in Europe*, 301 SCI. 1017 (2003).

[650] For a summary of the issues, *compare* Consuelo G. Erwin, Note, *Embryonic Stem Cell Research: One Small Step Forward for Science or One*

Although there remains great disagreement on the issue, it would be hard to deny that this is an issue that cannot reasonably be decided on the basis of purely scientific opinion.

Similarly, biodiversity is not solely a scientific issue; it implicates a wide range of other values.[651] We might override scientific doubts about some puzzles by shifting the debate to another scale of values. Take for example, the issue of whether "umbrella species" is a valid scientific concept.[652] We might validly decide to give high priority to the conservation of those large, charismatic species that are useful in educating children to love nature, such as redwoods and pandas, because we think it is important to promote biophilia in our children even if we can't be sure that the role these species play in overall biodiversity is particularly important.[653]

Another potential example of an override might be the issue of hybrids.[654] In recent years there has been significant interest in revamping American conservation policies, which have refused any protection for hybrids because they were not "natural."[655] Today, some biologists stress that hybridization is a natural part of the evolutionary process, and they suggest that "natural hybrids" should be protected as a means of protecting an important evolutionary process.[656] Other biologists worry that scientific disagreement over the various degrees of potential hybridization makes it impractical to try to provide protection.[657] On the other hand, agricultural and horticultural interests see important economic values in preventing the extinction of older varieties of the plants and animals, preserving genetic material so as to meet unpredictable disruptions, such as new diseases.[658] These interests

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*Giant Leap Back for Mankind?*, 2003 U. ILL. L. REV. 211 (2003) *with* Jason R. Braswell, Note, *Federal Funding of Human Embryo Stem Cell Research: Advocating a Broader Approach*, 78 CHI.-KENT L. REV. 423 (2003).

[651] *See, e.g.*, *supra* notes 9-11 and accompanying text.

[652] *See supra* notes 177-194 and accompanying text.

[653] Jepson & Canney, *supra* note 177, at 226.

[654] *See supra* notes 454-479 and accompanying text.

[655] *See generally* Allendorf et al., *supra* note 456.

[656] *Id.* at 621. (an exception would be made where a human-initiated hybrid contains the only remnants of the genetic information of an otherwise extinct species).

[657] *See* AVISE, *supra* note 125, at 296-97.

[658] Whitman, *supra* note 470. Numerous "seed banks" and collections of rare specimens of plants are in existence around the world. *See, e.g.*, ROYAL

are just as motivated to protect hybrids as original species, for similar reasons.[659] Here the potential economic benefits of preserving hybrid diversity might override any academic scientific debate.

### C. *Choice*

In many instances, our laws choose to believe one particular scientific viewpoint, even though there are dissenting opinions, on the ground that a majority opinion is contested only by a small and less well renowned group of scientists.[660] Where we conclude that the weight of scientific opinion is sufficiently strong in favor of a particular solution, the law can simply decree that science has resolved the issue, and that the view of those who disagree is merely "junk science."[661] Environmental law has long used this approach, labeling new scientific theories as merely untested hypotheses until they become widely accepted by the scientific community—as was the case in regard to the theory of stratospheric ozone depletion.[662] In retrospect, of course, many

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BOTANICAL GARDENS, KEW, MILLENNIUM SEED BANK PROJECT, *at* http://www.rbgkew.org.uk/msbp/index.html (last visited Apr. 1, 2004); CALIFORNIA RARE FRUIT GROWERS SEED BANK, *at* http://www.crfg.org/seedbank.html (last visited Apr. 1, 2004). For a discussion of efforts to protect native bee species by commercial honey producers, see GRETCHEN C. DAILY & KATHERINE ELLISON, THE NEW ECONOMY OF NATURE: THE QUEST TO MAKE CONSERVATION PROFITABLE 205-20 (2002).

[659] *See, e.g.*, Bao-Rong Lu, *Conservation and Sustainable Use of Biodiversity in Wild Relatives of Crop Species*, *in* BIODIVERSITY: BIOMOLECULAR ASPECTS OF BIODIVERSITY AND INNOVATIVE UTILIZATION 23, 24 (Bilge Şener ed., 2002) (wild relatives of crop species, including hybrid swarms between wild and crop species, are very important sources of material for broadening the genetic background of crop species).

[660] *See, e.g.*, Daubert v. Merrell Dow Pharmaceuticals, 509 U.S. 579, 595 (1993).

[661] On the origin of the term, see PETER HUBER, JUNK SCIENCE IN THE COURTROOM 24-38 (1991). Of course where the views of the small group of dissenting scientists are supported by powerful economic interests, some policymakers may apply similar epithets to the majority view. Senator Inhofe, of the oil-producing state of Oklahoma, has referred to the majority view on climate change as "phony science." Andrew C. Revkin, *Politics Reasserts Itself in the Debate Over Climate change and Its Hazards*, N.Y. TIMES, Aug. 5, 2003, at D3.

[662] The "success at achieving controls of ozone depleting chemicals offers a kind of 'poster boy' model for viewing how science might inform successful environmental policy." RICHARD O. BROOKS ET AL., LAW AND ECOLOGY: THE RISE OF THE ECOSYSTEM REGIME 239 (2002).

new theories have become accepted over time,[663] but others continue to lurk in the background; consider, for example, the controversy over whether electromagnetic fields created by power lines create health problems.[664] The inability to find any clear causal connection between power lines and human illness has led policymakers to choose to treat contrary theories as unreliable despite lingering concern that there might be some correlation between proximity to power lines and childhood leukemia.[665]

Among the scientific puzzles about biodiversity, the issue of redundancy might be a appropriate area in which to choose among differing scientific opinions.[666] I think that the law should reject the idea that any species is expendable because other similar species can perform the same ecological functions. The anti-redundancy scientists make a convincing case that the appearance of redundancy is often a temporary phenomenon, and that we cannot safely predict that any species will never prove to be essential to ecological processes at some point in the future.[667]

We might also choose, in a different way, between those biologists who favor priority for unique species and those who take the exact opposite view, favoring priority for those species with

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[663] Vandermeer, *supra* note 529, at 56-57 ("We must fear, especially in the academic realm, being judged as having a lunatic idea. No Vatican will banish us from our university, but the contemporary equivalent of the Vatican of Galileo's times is contained within the Academy, and our ideas are easily banished from serious consideration from the current judges whether an argument is lunatic or prescient.").

[664] *See* FRED BOSSELMAN ET AL., ENERGY, ECONOMICS AND THE ENVIRONMENT: CASES AND MATERIALS 675-78 (2000).

[665] *See generally* NAT'L INST. OF ENVTL. HEALTH STUDIES, ASSESSMENT OF HEALTH EFFECTS FROM EXPOSURE TO POWERLINE FREQUENCY ELECTRIC AND MAGNETIC FIELDS (Christopher Portier & Mary Wolfe eds., 1998.)

[666] *See* discussion *supra* accompanying notes 371-385.

[667] *See, e.g.*, Wardle & Van der Putten, *supra* note 380, at 166-67 (citations omitted):

> Terrestrial ecosystems are not static entities, and even if species richness is unimportant as an ecosystem driver at a given point in time, the issue remains as to whether diversity is important under changing environmental conditions through buffering ecosystem properties and process rates.
>
> . . . .
>
> For example, subordinate plant species which are functionally unimportant at a particular point in time may confer an element of stability on above-ground and below-ground processes following a change in environmental conditions that adversely affects the dominant species relevant to the subordinate species.

prolific evolutionary characteristics.[668] I would choose to allow these ideas to cancel each other out and make no priority distinction on the basis of either uniqueness or evolutionary potential, at least until such time as the arguments for one side or the other become more powerful. At this time there is not enough scientific support to give priority to either rapidly evolving species or to taxonomically unique species, so the law should treat them the same as all other species.[669] A study of various lists of species priority concluded that priority-setting

> inevitably reflects the preferences and predispositions of the commissioning institution, including (almost inevitably) the way in which the institution contemplates its funding opportunities . . . The fact is that priority-setting is seriously problematic and potentially divisive, with each commissioning institution promoting the merits of its own rationale, methods and data sets, but none comfortable to admit the limitations of its own exercise or, worse, the actively competitive and aggressive position underlying the adoption of its results. Inevitably, however, priority-setting involves both the conscious and unwitting exclusion of species, phenomena, habitats and issues which do not fit the declared remit of the commissioning institution.[670]

Another issue for which choice is appropriate is the issue of new species. Biodiversity has always been increased through the development of new species.[671] How could we say that only old species deserve protection and not new species?[672] The growing

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[668] *See* discussion at notes 235-245 *supra*.

[669] *See* SLOBODKIN, *supra* note 11, at 138, stating:

> I certainly am not against the preservation of species diversity. However, I cannot understand how the study of diversity in the abstract will lead to intellectual or practical advantages commensurate with the money, time, energy, and propaganda with which it has been surrounded. . . . Hans Christian Andersen['s] story of the emperor's new clothes comes . . . to mind.

[670] Georgina M. Mace & Nigel J. Collar, *Priority-Setting in Species Conservation*, *in* CONSERVING BIRD BIODIVERSITY: GENERAL PRINCIPLES AND THEIR APPLICATION 61, 72-73 (Ken Norris & Deborah J. Pain eds., 2002).

[671] For an interesting summary of the ecological theory relating to trends in potential future species creation, see ROSENZWEIG, *supra* note 552, at 101-41.

[672] A major deterrent to protection of new species is the fact that many of them are evolving in response to our attempts to exterminate them, as in the case of insects and bacteria. Can valuable information be obtained from harmful species that develop resistance to our attempts to suppress them? Should we avoid driving them to extinction even if we could? *See* discussion *supra* at notes

awareness of the rapidity with which some kinds of organisms can evolve means that the law will be forced to address more frequently the issue of whether to protect newly-evolving species.[673]

## D. *Triage*

Lack of available funds often forces lawmakers to choose to expend funds on only those scientific issues that they deem most urgent. The medical term "triage" is widely used to characterize such situations. It refers to the practice of using scarce medical resources to treat the patients with the best chance of recovery.[674] This type of priority-setting has been widely used in environmental law in, for example, selecting the particular chemicals for which standards will be set.[675] For example, when the Toxic Substances Control Act was adopted in 1976, it set mandatory regulatory standards for only one chemical out of the thousands of possibly toxic chemical substances that are now used in industry.[676]

In some cases—probably all too many cases—our ability to address biodiversity may be so hampered by lack of resources that we will need to make deliberate decisions not to bother to try to protect certain kinds of biodiversity.[677] For example, it may be

572-576.

[673] At present, the ESA's protection for "separate populations" of a species may provide some protection, at least to the extent that speciation is allopatric; i.e., the result of geographic separation. MICHAEL J. BEAN & MELANIE J. ROWLAND, THE EVOLUTION OF NATIONAL WILDLIFE LAW 200-01 (3d ed. 1997). To the extent that some differentiation of species may result from organisms choosing separate ecological niches within the same geographic area (sympatric speciation), the agencies may need to consider whether to subdivide an existing species. Since 1988, field studies have confirmed the existence of more sympatric speciation that had been expected. Sara Via, *Sympatric Speciation in Animals: The Ugly Duckling Grows Up*, 16 TRENDS IN ECOLOGY AND EVOLUTION 381, 382-83 (2001).

[674] The term was originally used in World War I to describe the process of sorting battle victims into three classes based on their chances of survival. It is now used broadly to describe the assigning of priority order to projects on the basis of where funds and resources can be best used or are most needed. MERRIAM WEBSTER'S COLLEGIATE DICTIONARY 1260 (10th ed. 1993).

[675] *See, e.g.*, Safe Drinking Water Act, 42 U.S.C. § 300g-1(b)(1)(B) (1994) (the process for selecting the contaminants for which standards are to be set).

[676] *See* FREDERICK R. ANDERSON ET AL., ENVIRONMENTAL PROTECTION: LAW AND POL'Y 840-61 (3d ed. 1999).

[677] The National Center for Ecological Analysis and Synthesis at the University of California, Santa Barbara, has an interesting research project dealing with this issue of setting priorities and making decisions on conservation

necessary to ignore some "sibling species" insofar as protection of biodiversity is concerned.[678] To the extent that particular sibling species cannot be distinguished by cost-effective methods, the law may simply need to lump them together until scientists come up with a practical way to separate them in the field.[679]

Indicator species may be another example. In general, scientists find it difficult to agree on criteria for identifying indicator species.[680] But insofar as the practical value of indicator species is concerned, Oliver Houck's extensive experience and empirical analysis suggests that indicator species are a necessary catalyst for agency action.[681] So as a practical matter we may need to focus on a few species that we hope are indicators because we lack the resources to identify and protect all of the possible candidates.[682] Under this approach, we can only hope that scientists find that some cuddly panda-like creature or some beautiful flowering plant turns out to be the indicator species for an area rather than some nematode,[683] or a mite,[684] or even a bacterium.[685]

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risk management. *See* NAT'L CTR. FOR ECOLOGICAL ANALYSIS AND SYNTHESIS, RESEARCH PROJECTS, *at* https://www2.nceas.ucsb.edu/admin/db/web.plist (last visited Feb. 14, 2004).

[678] Sibling species are those that appear identical to humans in the field but reproduce only with those of their own kind based on the recognition of certain factors that are either not apparent to humans at all, or at least are not distinguishable by human observers under natural conditions. *See* discussion at notes 248-250 *supra*.

[679] *See* discussion at notes 251-257 *supra*.

[680] Simberloff, *supra* note 215, at 247; Fleishman et al., *supra* note 181, at 1490 ("In light of the increasingly pervasive and often indiscriminate application of terms such as ecosystem health, indicator species, and umbrella species, we emphasize that no one focal species or taxonomic group can carry the full load as a surrogate in conservation planning.").

[681] Houck, *supra* note 223, at 976.

[682] *See* Reed F. Noss, *Indicators for Monitoring Biodiversity: A Hierarchical Approach*, 4 CONSERVATION BIOLOGY 355, 357-58 (1990).

[683] Perhaps illustrating the lack of practicality in this approach, nematodes in fact do appear to be important in ecosystems. *See, e.g.*, B. C. Verschoor et al., *Could Plant-Feeding Nematodes Affect the Composition Between Grass Species During Succession in Grasslands under Restoration Management?* 90 J. OF ECOLOGY 753, 753 (2002); J. G. Baldwin, *Nematodes: Pervading the Earth and Linking All Life*, *in* NATURE AND HUMAN SOCIETY: THE QUEST FOR A SUSTAINABLE WORLD 176, 187-89 (Peter H. Raven ed., 2000). *See also* Stein et al., *supra* note 86 at 60 ("Nematodes are perhaps the most abundant organisms on earth."); Scott L. Gardner, *Worms, Nematoda*, *in* 5 ENCYCLOPEDIA OF BIODIVERSITY 843 (Simon A. Levin ed., 2001).

[684] Like nematodes, mites appear to be ecologically important. R. B.

Each of these four approaches—postponement, override, choice, and triage—may be ways of resolving the scientific puzzles of biodiversity for the moment, but a much more satisfactory approach in the long run is to obtain the best scientific advice and feed it back into the policymaking process through familiar systems that have lately become called "adaptive management."

### E. *Adaptive Management*

The term adaptive management has become the trendy word for an old kind of planning[686] that recognizes the existence of unsolved puzzles.[687] Such planning requires continual feedback of

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Halliday, *Global Diversity of Mites*, *in* NATURE AND HUMAN SOCIETY: THE QUEST FOR A SUSTAINABLE WORLD 192 (Peter H. Raven ed., 2000).

[685] Embley et al., *supra* note 180, at 21. Whether in technical or popular writing, there is agreement that little is known about microorganisms, perhaps in part due to their lack of charisma. *Compare* Juha Mikola et al., *Biodiversity, Ecosystem Functioning and Soil Decomposer Food Webs*, *in* BIODIVERSITY AND ECOSYSTEM FUNCTIONING: SYNTHESIS AND PERSPECTIVES 169 (Michel Loreau et al. eds., 2002) (arguing that information on soil decomposer diversity is skimpy because of historical neglect of decomposers by conservation inventories, lack of methodologies to identify and quantify the diversity of decomposers, especially the unculturable microbes, and the time-consuming nature of soil organism taxonomy. Because species richness in decomposer food webs is high, it has been speculated that most species are redundant, but this is largely assumed without evidence, and not universally agreed), *with*

> The tiny soil-dwelling organisms are still so unstudied that any shovelful of dirt is likely to contain two or three new species. I do not know, and I do not think it is known, how widely or narrowly species of forest soil organisms are distributed. Is there a chance of wiping out a species if we plow a field or weedproof a lawn? Perhaps. Is there danger in this? Probably not. How do I know? I'm guessing.

SLOBODKIN, *supra* note 11, at 87.

[686] Machiavelli, for one, advised his prince to be prepared to change with the times

> for if one governs himself with caution and patience, and the times and affairs turn in such a way that his government is good, he comes out prosperous: but if the times and affairs change, he is ruined because he does not change his mode of proceeding, . . . whether because he cannot deviate from what nature inclines him or also because, when one has always flourished by walking on one path, he cannot be persuaded to depart from it.

NICCOLÕ MACHIAVELLI, THE PRINCE 100 (Harvey C. Mansfield, Jr. trans., 1985).

[687] For information on the experience of resource managers using adaptive management, see ADAPTIVE MANAGEMENT PRACTITIONERS' NETWORK, TAKING STOCK, *at http://www.iatp.org/AEAM/describe.html* (last visited Feb. 14, 2004).

new information into the planning process.[688] The current revival of adaptive planning and management theory was stimulated by the failure of then-popular theories of strategic planning to survive the economic turmoil that began with the oil embargo of 1973 and the floating exchange rates, high inflation, and increasing international competition that followed; "organizations learned from practical experience that simple extrapolations of history and cadres of professional planners failed to lead to innovation, adaptation to change, or even survival."[689]

Canadian management professor Frances Westley advocates adaptive planning for natural resources as a way of managing an ecosystem that is "responsive to the variations, rhythms, and cycles of change natural in [the ecosystem and] able to react quickly with appropriate management techniques."[690] She points out that adaptive management has "an appeal that transcends the management of ecosystems. In the past decade—in response to radical shifts in world economies, resource bases, population dynamics, and competitive structures—private- and public-sector organizations in all domains have wrestled with similar challenges."[691] She describes adaptive management as a "learning-led" strategy because learning introduces redundancies and inconsistencies into the organizational structure that "may modify the conclusive nature of existing ideologies."[692] Or as J. B. Ruhl puts it, if the management process offers no incentive to experiment, any "learning that has not yet materialized into tangible performance results . . . is stultified."[693] As a result of arguments like these, emphasis has shifted from the plan as document to the plan as a process through which new information

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I have expressed some thoughts about adaptive management at greater length in Fred Bosselman, *A Role for State Planning: Intergenerational Equity and Adaptive Management*, 12 U. FLA. J.L. & PUB. POL'Y 311 (2001).

[688] *See* Ruhl, *supra* note 225, at 942-43.

[689] Richard P. Rumelt et al., *Fundamental Issues in Strategy*, *in* FUNDAMENTAL ISSUES IN STRATEGY: A RESEARCH AGENDA 9, 20 (Richard P. Rumelt et al. eds., 1994). *See also* Gerald R. Ford, *Science Advice to the President*, *in* SCIENCE ADVICE TO THE PRESIDENT, CONGRESS, AND JUDICIARY 140, 143 (William T. Golden ed., 2d ed. 1995).

[690] Frances Westley, *Governing Design: The Management of Social Systems and Ecosystem Management*, *in* BARRIERS AND BRIDGES TO THE RENEWAL OF ECOSYSTEMS AND INSTITUTIONS 391, 394 (Lance H. Gunderson et al. eds., 1995).

[691] *Id*.

[692] *Id*. at 401, 413, 417.

[693] Ruhl, *supra* note 225, at 988.

is analyzed and fed back within the organization to enable decisions to be made promptly as the need arises.[694]

Where scientific puzzles are involved, the federal government has long used a variety of adaptive procedures for obtaining scientific advice and feeding it back into the decision making process. For many of the puzzles discussed in this Article, the best course would be to set in motion these procedures.

1. *Procedures for obtaining scientific advice*

The procedures by which the federal government obtains advice on scientific issues are manifold and always seem to be in flux as administrations change. Of particular importance are (a) the office of the science adviser to the president, (b) the agencies that provide scientific advice to Congress, (c) the scientific advisory boards of various administrative agencies, and (d) the National Academies complex.

a. *The science adviser*

Within the executive branch, since 1951, the President has had an official "science adviser'[695] who now heads the Office of Science and Technology Policy (OSTP).[696] The initial concerns that prompted the creation of a science adviser revolved around nuclear energy and space exploration.[697] Consequently, science advisers have historically been particularly concerned with the physical sciences and engineering.[698] Each president since that time has made an individual judgment on the exact role that the adviser played in his administration.[699]

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[694] J.C. SPENDER, INDUSTRY RECIPES: AN ENQUIRY INTO THE NATURE AND SOURCES OF MANAGERIAL JUDGMENT 66-67 (1989.)

[695] D. ALLAN BROMLEY, THE PRESIDENT'S SCIENTISTS: REMINISCENCES OF A WHITE HOUSE SCIENCE ADVISER 1 (1994).

[696] *Id*. at 4 (noting that the office of the science adviser predates the creation of the OSTP, which occurred in 1976). On the current organization of OSTP, see generally OFFICE OF SCI. AND TECH., WHO WE ARE, *at* http://www.ostp.gov/html/_whoweare.html (last visited Mar. 31, 2004).

[697] *See generally* GREGG HERKEN, CARDINAL CHOICES: PRESIDENTIAL SCIENCE ADVISING FROM THE ATOMIC BOMB TO THE SDI (rev. ed. 2000).

[698] The science adviser's office has always been staffed and advised primarily by physicists. BROMLEY, *supra* note 695. President Clinton's science adviser, Jack Gibbons, was also a nuclear physicist, but his staff included experts with background in the biological as well as the physical sciences. HERKEN, *supra* note 697, at 218-19; GIBBONS, *supra* note 648.

[699] *See, e.g.*, Gerald R. Ford, *supra* note 689, at 142 ("There is a great worry

The current head of the office is Dr. John H. Marburger, a nuclear physicist, former head of the Brookhaven National Laboratory, and president of the State University of New York at Stony Brook.[700] He took office late in 2001[701] and his role in the administration is undoubtedly still evolving, but media reports have raised doubts about his status in the White House pecking order after his office was moved out of its traditional place in the Old Executive Office Building.[702] Shortly after receiving Senate confirmation he eliminated two of the four senior positions at OSTP, including the associate director for environmental science.[703]

The 1976 legislation creating the OSTP provided for the creation of a President's Scientific Advisers' Council (PSAC),[704] to be staffed by OSTP but reporting directly to the President, although not all presidents have appointed such advisers.[705] On September 30, 2001, President Bush issued an executive order creating a new group of advisors to the science adviser, the President's Council of Advisors on Science and Technology (PCAST).[706] Whereas the earlier PSACs were all scientists, only one member of the current PCAST is a working scientist; the

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about the big surprises. Presidents don't like surprises. Each one wants both to be the first to hear bad news so they can prepare to handle it, and to know about good news so they can take advantage of it.").

[700] OFFICE OF SCI. AND TECH. POL'Y, WHAT WE DO, *at* http://www.ostp.gov/html/_whatwedo.html (last visited Feb. 18, 2004).

[701] *See, e.g.*, *An Interview with John Marburger; Terrorism, Money, Contacts Top Science Adviser's Agenda*, 294 SCI. 1642 (2001).

[702] Chris Mooney, *Political Science: The Bush Administration Snubs its Science Adviser*, THE AM. PROSPECT, Dec. 3, 2001, at 28-29. *See also* BROMLEY, *supra* note 695 ("Until you have spent time in Washington you do not fully realize that people will kill for such space . . . .").

[703] Andrew Lawler, *Marburger Shakes Up White House Office*, 294 SCI. 973 (2001). The first President Bush had appointed a distinguished biologist as associate director for life sciences. BROMLEY, *supra* note 695.

[704] Since 1993, the office of the science adviser has also been assisted, at least on paper, by a National Science and Technology Council (NSTC), which brings together the top scientific people in the various federal agencies. Exec. Order No. 12,881, 58 Fed. Reg. 62,491 (1993). *See also* OFFICE OF SCI. AND TECH. POL'Y, NATIONAL SCIENCE AND TECHNOLOGY COUNCIL, *at* http://www.ostp.gov/NSTC/html/NSTC_Home.html (last visited March 7, 2004). The NSTC, and its predecessors under various names, have occasionally been used when extensive interagency cooperation was desired on scientific issues. HERKEN, *supra* note 697.

[705] BROMLEY, *supra* note 695.

[706] Exec. Order 13,226, 3 C.F.R. 792-93 (2002).

majority are from industry and the rest are academic administrators, although some have science backgrounds.[707] In the fall of 2002, PCAST urged the White House to propose budgetary increases for the physical sciences and engineering to counterbalance the proposed increases in life sciences research.[708] Given these developments, on balance it seems unlikely that the current OSTP would take the lead in trying to resolve issues of biodiversity policy.

b. *Scientific advice to Congress*

From 1973[709] to 1995, Congress relied on three separate sources of scientific and technological assessment: the General Accounting Office (GAO),[710] the Congressional Research Service (CRS),[711] and the Office of Technological Assessment (OTA).[712]

The OTA was specifically assigned the responsibility of

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[707] David Malakoff, *Venture Capitalist to Lead Science Panel*, 292 SCI. 28 (2001). For other examples of the administration's appointment of scientists working for industry to advisory panels, see Rep. Henry Waxman, *Politics & Science: Investigating the State of Science under the Bush Administration*, *at* http://www.house.gov/reform/min/politicsandscience (last visited March 7, 2004).

[708] D. Allan Bromley & Michael S. Lubell, *Science's Growing Political Strength*, 19 ISSUES IN SCIENCE AND TECHNOLOGY Summer 2003, at 13, 15, *available at* http://www.issues.org/issues/19.4/bromley.html (last visited March 7, 2004).

[709] The Office of Technology Assessment was created by the Technology Assessment Act of 1972, Public Law 92-484, § 2(c)(1), but it did not receive funding until 1973. CARNEGIE COMMISSION ON SCI., TECH., AND GOV'T, SCIENCE, TECHNOLOGY AND CONGRESS: ANALYSIS AND ADVICE FROM THE CONGRESSIONAL SUPPORT AGENCIES § 3.1 (1991), http://*www.carnegie.org/sub/pubs/science_tech/congagcy.txt* (last visited March 7, 2004).

[710] BRUCE A. BIMBER, THE POLITICS OF EXPERTISE IN CONGRESS: THE RISE AND FALL OF THE OFFICE OF TECHNOLOGY ASSESSMENT 88-92 (1996); CARNEGIE COMMISSION ON SCI., TECH., AND GOV'T, *supra* note 709, § 3.3.

[711] An arm of the Library of Congress, the CRS's role is to assemble and analyze previous research rather than to undertake research itself. L. Christopher Plein & David J. Webber, *The Role of Technology Assessment in Congressional Consideration of Biotechnology*, *in* SCIENCE, TECHNOLOGY AND POLITICS: POLICY ANALYSIS IN CONGRESS 123, 126 (Gary C. Bryner ed., 1992). Its studies may be kept confidential by Congress and are not subject to peer review. CARNEGIE COMMISSION ON SCI., TECH., AND GOV'T, *supra* note 709, § 3.2. *See also* BIMBER, *supra* note 710 at 79-83.

[712] Plein & Webber, *supra* note 711. In addition, the Congressional Budget Office advises Congress on budgetary issues relating to science but would not opine on science policy. BIMBER, *supra* note 710, at 83-88.

informing Congress on issues of science and technology.[713] It issued one of the early reports on biological diversity shortly after the initial Smithsonian conference on biodiversity.[714] The Republican Congress that took office in 1995 was unhappy with the agency for reasons which remain obscure and controversial.[715] The agency had antagonized many industries, particularly agribusiness, by presenting a wide variety of points of view in its reports to Congress.[716] In the fall of 1995, Congress abolished OTA and it went out of business.[717] It is not likely that either the GAO or the CRS would try to resolve biodiversity issues.

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[713] BIMBER, *supra* note 710, at 26.

[714] OFFICE OF TECH. ASSESSMENT, TECHNOLOGIES TO MAINTAIN BIOLOGICAL DIVERSITY (1987). *See also* discussion at note 17 *supra*.

[715] One observer concluded that Congress chose OTA simply because it wanted to show that it could close down a congressional agency, and the OTA was the most recently created with the smallest cadre of supporters. BIMBER, *supra* note 710, at 69-77. But another observer suggests that the abolition of OTA was part of a response to what one observer has called "an emerging antiscience and even antirational bias in public opinion" resulting from "skepticism and bewilderment engendered by media attention to 'junk science' [and the] conflicting claims for new health cures, miracle diets and so forth." HERKEN, *supra* note 697. For comments on the continuing attempts of Congress to attack scientific results that their powerful constituents dislike, see Wendy E. Wagner, *The 'Bad Science' Fiction: Reclaiming the Debate over the Role of Science in Public Health and Environmental Regulation*, 66 LAW & CONTEMP. PROB. 63 (2003); Donald T. Hornstein, *Accounting for Science: The Independence of Public Research in the New, Subterranean Administrative Law*, 66 LAW & CONTEMP PROB. 227 (2003).

[716] Plein & Webber, *supra* note 711, at 127-28.

[717] Warren E. Leary, *Congress's Science Agency Prepares to Close Its Doors*, N.Y. TIMES, Sept. 24, 1995, § 1, at 26. OTA shut down on September 29, 1995. Barbara Rosewicz, *Today's Last Rites for Small Technology Agency Mark the Start of a 'Wrenching' and Historic Shift*, WALL ST. J., Sept. 29, 1995, at A16. *See also* Robert L. Glicksman & Stephen B. Chapman, *Regulatory Reform and (Breach Of) the Contract with America: Improving Environmental Policy or Destroying Environmental Protection?*, 5 KAN. J.L. & PUB. POL'Y 9, 19 (1996), stating:

> Republican supporters of regulatory reform have made it more difficult to premise environmental policy decisions on any science, much less "good science." The first session of the 104th Congress voted to shut down the Office of Technology Assessment, a research arm of Congress which was established during the Nixon Administration contemporaneously with the birth of much of the current federal environmental regulatory edifice, and which has been widely praised for its impartial advice to members of Congress of both parties.

c. *Agency advisory boards*

Many federal agencies have their own "science advisory boards" that are used in a wide variety of ways.[718] For example, the Environmental Protection Agency has an active Science Advisory Board with its own staff and committees that have prepared reports on many different pollution issues.[719] The National Oceanographic and Atmospheric Agency (NOAA) also has a distinguished Science Advisory Board,[720] but it meets just three times a year and apparently provides advice informally.[721]

The federal agency with the most direct involvement in biological issues is the Department of the Interior (DOI). Many biologists are employed within the various agencies of DOI, such as the National Park Service[722] and the FWS.[723] In 1993, Secretary of the Interior Bruce Babbitt created a new entity, the National Biological Survey (NBS).[724] His objective was to insulate basic

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718 *See generally* BRUCE L. R. SMITH, THE ADVISERS: SCIENTISTS IN THE POLICY PROCESS (1992).

719 *See* EPA, EPA SCIENCE ADVISORY BOARD, *at* http://www.epa.gov/sab (last visited March 7, 2004). The history of EPA's SAB is discussed in Smith, *supra* note 718, at 68-100. An ecology committee of the SAB has been doing some interesting work on the assessment of ecological risks. *See* SCIENCE ADVISORY BOARD, EPA, A FRAMEWORK FOR ASSESSING AND REPORTING ON ECOLOGICAL CONDITION (2002) (EPA doc. no. EPA-SAB-EPEC-02-009). For an assessment of EPA's science advice during the 1980s, see generally SHEILA JASANOFF, THE FIFTH BRANCH: SCIENCE ADVISERS AS POLICYMAKERS (1990). Former EPA general counsel suggests that a better way to enhance the status of science at EPA would be to designate a "chief science officer" as an advisor to the administrator. E. Donald Elliott, *Strengthening Science's Voice at EPA*, 66 LAW & CONTEMP. PROB. 45, 53 (2003).

720 *See* NAT'L OCEANIC AND ATMOSPHERIC ADMIN., NOAA'S SCIENCE ADVISORY BOARD, *at* http://www.sab.noaa.gov (last visited March 7, 2004).

721 *See* NOAA., NOAA'S SCIENCE ADVISORY BOARD: CALENDAR OF MEETINGS, *at* http://www.sab.noaa.gov/Meetings/meetings.html (last visited March 7, 2004).

722 *See* NAT'L PARK SERVICE, NATURE NET: BIOLOGICAL RESOURCES, *at* http://www1.nature.nps.gov/wv/indextxt.htm (accessed August 13, 2003) (describing examples of National Park Service biological work).

723 Attempts to provide outside "peer review" of the many Fish & Wildlife Service biologists have been resisted by the environmental organizations. *See* Eva Tompkins, Comment, *Reauthorization of the Endangered Species Act—A Comparison of Two Bills that Seek to Reform the Endangered Species Act: Senate Bill 768 and House Bill 2275*, 6 DICK. J. ENVTL. L. & POL'Y 119, 137-38 (1997).

724 Babbitt's proposal was supported by a report by the National Research Council endorsing the idea of an institution that would have the responsibility for "inventorying, mapping, and monitoring biotic resources; performing basic and

biological science advice to the DOI from the applied science advice given by other agencies in the Department.[725] Similar independence had been given long ago to the U.S. Geological Survey.[726]

However, the NBS proposal was beaten back by what Joseph Sax has called the "ecologically backward-looking" Congress that was elected in November, 1994.[727] There is now only a small unit within the United States Geological Survey that is currently doing the kind of basic biological research for which the NBS was intended.[728] I therefore doubt that DOI now is in a position to satisfactorily resolve controversial issues of biodiversity science.[729]

d. *The National Academies complex*

The one advisory agency that has consistently and successfully survived a wide range of political changes is the National Research Council (NRC), an arm of three nonprofit entities—the National Academy of Sciences, the Institute of Medicine, and the National Academy of Engineering.[730] The NRC was created in 1916 in response for the federal government's need for scientific information as World War I became imminent.[731] After World War II the NRC was established in its current form as a separate member of what is known as the "National Academies

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applied research on species, groups of species, populations, and ecosystems; and providing the scientific support and technical assistance needed for management and policy decisions in DOI." NAT'L RESEARCH COUNCIL, A BIOLOGICAL SURVEY FOR THE NATION viii (1994).

[725] John D. Leshy, *The Babbitt Legacy at the Department of the Interior: A Preliminary View*, 31 ENVTL. L. 199, 206 (2001).

[726] *See* Ruhl, *supra* note 26, at 574.

[727] Joseph L. Sax, *Comment on John Harte's Paper, "Land Use, Biodiversity, and Ecosystem Integrity: The Challenge of Preserving Earth's Life Support System,"* 27 ECOLOGY L.Q. 1003, 1009 (2001).

[728] *See* U.S. GEOLOGICAL SURVEY, BIOLOGICAL RESOURCES, *at http://biology.usgs.gov* (last visited March 7, 2004).

[729] Ironically, the science adviser to the first President Bush, D. Allen Bromley, had supervised the writing of an Executive Order for the President that would have created a National Center for Biological Diversity in DOI, but the effort became sidetracked in the Office of Management and Budget two days prior to President Clinton's inauguration. BROMLEY, *supra* note 695.

[730] NAT'L ACADEMIES, THE NATIONAL RESEARCH COUNCIL, *at* http://*www.nas.edu/nrc* (last visited March 7, 2004).

[731] RAYMOND C. COCHRANE, THE NATIONAL ACADEMY OF SCIENCES: THE FIRST HUNDRED YEARS, 1863-1963, 209-11 (1978).

complex."[732]

The NRC creates special committees of experts to respond to requests for advice by either Congress or agencies of the executive branch,[733] and to write reports, several of which have been cited in this Article.[734]

Given the political pitfalls over which official scientific advisers to the government must negotiate, the NRC continues be the most respected source of all forms of scientific and technological advice.[735] It is particularly strong in the area of biological sciences.[736] The members of the National Academies' Board on Life Sciences are highly respected scientists[737] and in 2002, for example, the Academies published a wide range of biological reports on issues ranging from the genetic status of Atlantic Salmon to the ecology of Yellowstone's northern range.[738] Of the available options, the NRC is the best equipped to study the puzzles of biodiversity in a thorough and credible manner.

## CONCLUSION: KEY QUESTIONS FOR FUTURE RESEARCH

Any of the puzzles discussed in this Article could be posed to the NRC, and eventually many of them probably will. My priority would go to two puzzles, #6 (species taxomony) and #8 (invasive

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[732] *Id*. at 246-56.

[733] NAT'L ACADEMIES, WHAT IS THE NATIONAL RESEARCH COUNCIL?, *at* http://www.nas.edu/about/faq3.html (last visited March 31, 2004) (noting committee members serve without pay).

[734] *See, e.g.*, *supra* notes 19, 55, 162, 386, 452, 641, 724.

[735] *See, e.g.*, John Brooks Slaughter, *A Case for Evaluating the Nature of Scientific and Technological Advice to the Federal Government*, *in* SCIENCE ADVICE TO THE PRESIDENT, CONGRESS, AND JUDICIARY 325, 326-27 (William T. Golden ed., 2d ed. 1995) (stating that the NRC "occupies and deserves an exalted place in the hierarchy of organizations participating in the process of recommending priorities for federal investments in science and technology"). Even a 1975 study by a colleague of Ralph Nader found much to praise in the NRC's work, though it disagreed with the conclusions of a number of their studies. *See* PHILLIP M. BOFFEY, THE BRAIN BANK OF AMERICA: AN INQUIRY INTO THE POLITICS OF SCIENCE 8-9 (1975).

[736] The first NRC study in this area was in 1920 and resulted in some of the early studies of the influence of air quality and climate on health. COCHRANE, *supra* note 731, at 261.

[737] *See* NAT'L ACADEMIES, BOARD ON LIFE SCIENCES: BOARD MEMBERS, *at* http://dels.nas.edu/bls/board.html (last visited March 7, 2004).

[738] *See generally* NAT'L RESEARCH COUNCIL, GENETIC STATUS OF ATLANTIC SALMON IN MAINE: INTERIM REPORT (2002); NAT'L RESEARCH COUNCIL, ECOLOGICAL DYNAMICS OF YELLOWSTONE'S NORTHERN RANGE (2002).

species), that pose imminent legal problems in the administration of biodiversity protection.

## PUZZLE #6:
## SHOULD WE CONTINUE TO UTILIZE THE TRADITIONAL CONCEPT OF SPECIES TO DETERMINE SPECIES RICHNESS AND SPECIES ENDANGERMENT, OR SHOULD WE SWITCH TO NEWER SYSTEMS OF CLASSIFYING ORGANISMS THAT RELY SOLELY ON THE SIMILARITY OF THEIR GENETIC LINEAGE?

The very basic issue of whether we should continue to use the Linnaean system of taxonomy ought not to be ignored or overridden, lest someone should persuade a judge that the Linnaean system is "junk science."[739] The extensive variation of scientific opinion would make it difficult for the law to make a defensible choice without scientific support.[740] The creation of a high-level scientific panel[741] to explore the various options available for modern systematics might therefore be the best way to resolve some of the uncertainty surrounding taxonomy. How should resource managers address the questions raised by molecular biology about our traditional concept of species? For example, what if phylogeneticists say that an existing species, which appears to be common, is really ten separate species that may be indistinguishable in the field, but include some that are likely to be quite rare? Conversely, what if some of the subspecies that we have expended considerable effort to protect turn out to be, from a genetic perspective, substantially identical? Resolution of these issues might take many years and would require a concerted and objective analysis by some group that has credibility among systematists.[742]

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[739] *See* Center for Biological Diversity v. Lohn, 296 F.Supp.2d 1223 (W.D. Wash. 2003); SLOBODKIN, *supra* note 11, at 209 (arguing that knowingly using bad science damages the future authority of science and encourages use of junk science in the future).

[740] *See* discussion *supra* at notes 327-353.

[741] *See supra* Part III.E.1.d.

[742] Holly Doremus, *Adaptive Management, the Endangered Species Act, and the Institutional Challenge of "New Age" Environmental Protection*, 41 WASHBURN L.J. 50, 89 (2001) (arguing there is a need to develop "institutions that will help us manage in a more scientifically rational manner"). For discussion of one such program, by the International Union of Biological Sciences, that hopes to achieve this objective, see Joel L. Craycraft, *Charting the*

**PUZZLE #8:**

**WHAT CRITERIA SHOULD BE USED TO DECIDE WHETHER A SPECIES OF PLANT OR ANIMAL HAS AN ADVERSE EFFECT ON BIODIVERSITY BECAUSE IT ARRIVED AT ITS PRESENT LOCATION BY THE WRONG METHOD OR AT THE WRONG TIME, OR BECAUSE IT HAS THE POTENTIAL OF BEING INVASIVE OR CREATING HYBRIDS?**

The issue of native species also needs such a process of research-driven adaptive management. Although the biologists' general distaste for exotic species understandably remains strong, the rationale for the distaste may not always be easy to justify in all situations.[743] The federal government's modest new initiative to increase the attention to invasive species makes good economic sense.[744] If the government's resources are to be spent wisely, though, there should be some consensus on the underlying scientific issues. The NRC has already given advice on some aspects of the nonindigenous species issue,[745] and should be asked to do so in more depth.

It is easy to document the damage to our economy from the expanding distribution of certain invasive species, but to lump all exotic species into the harmful category could cause significant harm both economically and ecological. Many exotics are very valuable, and in some instances, the movement of species to new locations is a natural and desirable way of adapting to environmental change.[746] All of these problems suggest the important need for scientifically-derived criteria that resolve them.[747]

All of these examples are merely illustrative of various approaches that the law could take to the puzzles of biodiversity. I am not suggesting that any of these puzzles can be easily solved, but I am optimistic that the law of biodiversity will continue to be refined advantageously if we give these issues serious thought.

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*Biosphere: Building Global Capacity for Systematics Science*, *in* NATURE AND HUMAN SOCIETY: THE QUEST FOR A SUSTAINABLE WORLD 374, 379-81 (Peter H. Raven ed., 1997).

[743] *See generally supra* Part II.B.1.

[744] The Invasive Species Act of 1996, 16 U.S.C. § 4701-4751 (2000), also directs federal agencies to attempt to control certain nonindigenous species.

[745] NAT'L RESEARCH COUNCIL, *supra* note 452 at 78-79.

[746] *See generally supra* Parts II.B.1 & II.C.3.

[747] *See* discussion at notes 386-453 *supra*.