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Biological Diversity Research: An Analysis

James W. McMinn

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P.O. Box 2680
Asheville, North Carolina 28802

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James W. McMinn
Biodiversity Coordinator
Southeastern Forest Experiment Station
Athens, Georgia

ABSTRACT

Biological diversity can be defined as the diversity of life, including the diversity of genes, species, plant and animal communities, ecosystems, and the interaction of these elements. The biodiversity issue arises from educated concern that the earth's diversity of life is threatened and is diminishing at an accelerated rate. An appropriate yardstick for biodiversity programs is how they affect the persistence of viable populations—populations that occur with sufficient gene pools, over large enough areas, with the requisite environments to perpetuate the organisms or ecosystems. Biodiversity is often **erroneously** understood to mean species diversity within stands or communities: the biodiversity concern is not about the local diversity of flora and fauna, but whether species or ecosystems are threatened. A coordinated program of biodiversity research could be structured under three overlapping subject areas: (1) threatened, endangered, and sensitive species; (2) restoration of missing, underrepresented, or declining communities; and (3) general principles and procedures for ecosystem restoration and perpetuation.

Keywords: Genes, endangered species, plant communities, animal communities, ecosystems.

Introduction

A scientist who responds to constituents' demands for research on a general subject must often begin by more clearly defining the surrounding issues. Biological diversity (biodiversity) is different because the issue has already been defined by knowledgeable professionals among those constituents (Hunter 1990; Lubchenco and others 1991; National Research Council Committee on Forestry Research 1990; Norse and others 1986). Another way in which biodiversity differs from some issues is that the program of an entire research organization could be structured around it. In ultimate application, the issue is about maintaining ecological or environmental health while producing necessary goods and services. Considerable confusion surrounds the biological diversity issue.

The purposes of this document are (1) to establish working definitions of biological diversity and the issues surrounding it consistent with the conclusions of our knowledgeable constituencies, and (2) to suggest a framework for an efficient, coordinated research effort.

Biological Diversity Defined

Biological diversity can be defined as the diversity of life, including the diversity of genes, species, plant and animal communities, ecosystems, and the interaction of these elements. More succinctly, "Biological diversity refers to the variety and variability among living organisms and the ecological complexes in which they occur" (Office of Technology Assessment 1987). Note that a useful, nontechnical synonym for "diversity" is "variety." These definitions alone provide only a hint about the issue and little guidance for research or management.

The Biological Diversity Issue

The biodiversity issue arises from educated concern over the rapid rate at which the earth's species are disappearing or coming close to extinction and the real possibility that entire ecosystems will be lost. Norse and others (1986) discussed widely recognized reasons for perpetuating biological diversity under the general subject areas of (1) the products of life, (2) ecosystem services, (3) a less obvious need for living things, and (4) ethics and stewardship. The phrase "products of life" denotes a recognition of continuing human dependence on new, as well as traditional, plants and animals for necessities of life. New food products include kiwi fruit, napa cabbage, and monkfish. Soybeans are a relatively recent crop and the heavy use of tomatoes—long thought poisonous by Europeans—is relatively new. Genes from primitive varieties and wild relatives of domesticated species are used to improve productivity as well as to enhance tolerance to environmental stress, pests, and diseases. These gene pools will become more important with further development of genetic engineering. Pollination of many plants of direct significance to humans depends on an array of insects. Animals, fungi, and microorganisms are of growing importance in biological pest control. Wild populations continually provide new sources of medicines, energy, and industrial feedstocks for products such as high-quality lubricants. Ecosystem services include the most basic life-support systems; air, water, and soils. Natural ecosystems play a critical role in water purification, atmospheric composition, soil formation and stabilization, flood control, and amelioration of global climate. The less obvious need for living things refers to the beneficial effects of animals and natural landscapes on human health and well-being. When people are allowed to hold and pet dogs, for example, their blood pressure and pulse rates are reduced, and patients whose windows face trees recover faster than those whose windows face buildings. Related to this is the popularity of zoos, botanical gardens, aquaria, and the many forms of outdoor recreation. The ethics and stewardship aspect is not linked to human benefits. Increasing numbers of people simply believe that perpetuating biological diversity is the right thing to do. Whether this ethical concern is based on science or religion, they are uncomfortable about eliminating life forms because living things, they believe, have a right to exist. They feel that human dominance of the planet confers an associated responsibility for stewardship. In short, the reasons for perpetuating biodiversity are varied, backed by a good bit of scientific evidence, and politically appealing.

A key concept associated with biodiversity is that of viable populations—populations that occur with sufficient gene pools, over large enough areas, with the requisite environments to perpetuate the organisms or ecosystems. An appropriate yardstick for biodiversity programs is how they affect the persistence of viable populations, rather than how they affect local diversity per se. In the ecosystem context, it is vital to maintain structure and function as well as taxonomic composition. Ecologists have defined the general problem (Wilson 1985) and have formally addressed suggested approaches for forest management generally (Hunter 1990) and for national forest management specifically (Norse and others 1986). The National Research Council Committee on Forestry Research (1990) identified the loss of biological diversity as one of the major issues that society faces concerning forests. The Ecological Society of America proposes biological diversity as one of the three major priorities for ecological research (Lubchenco and others 1991). The issue is mentioned frequently in the press. Jerry Adler, writing in the December 31, 1990, Newsweek, noted:

> . . . EPA is likely to devote an increasing proportion of its resources to life on earth—and relatively less to life in, say, the dioxin-tainted town of Times Beach, Mo. The inhabitants of the former, unlike the latter, have nowhere else to go.
>
> The agency has already laid the groundwork for this reassessment. In a report last fall ("Reducing Risk"), the agency's Science Advisory Board identified four "relatively high-risk" environmental priorities in the coming years, all of them global in scope: climate change, ozone depletion, **destruction and alteration of wildlife habitat, and species extinction.** [*emphasis added*]

Adler also noted that many of EPA's traditional concerns, including herbicides and pesticides, toxic pollutants in general, and acid precipitation are in the "relatively medium-risk" category. The "relatively low-risk" category includes groundwater pollution, acid runoff to surface water, thermal pollution (of waters from power plants), and oil spills. The EPA rankings indicate that biological diversity is perceived as a high-priority political and scientific issue.

For clarification there is a need to explicitly recognize what biological diversity is not. Biological diversity is not about maximizing the number of species within a given area (Noss 1990): in this context it is irrelevant, for example, to refer to the biological diversity of a forest stand. Neither is it about maximizing the variety of communities, age classes, or management regimes in a spatial pattern of land allocation. It does not imply the designation of preserves or natural areas unless such designation is necessary to perpetuate some species or communities (Soulé and Kohm 1989).

Biological diversity is not a new discipline, but it does provide an alternative point of view that can help to guide and coordinate natural resources research and management. It is a new way of viewing the sustainability of all natural resources. It provides a philosophical basis for arriving at an acceptable balance when ecological health is in conflict with commodity production or other land uses. **A primary research challenge is to determine the types and levels of management compatible with the perpetuation of viable populations and ecological units.**

Traditional Diversity Definitions and Measures

Definitions and measures are discussed for two reasons. First, there is a general need to know and distinguish between the technical use of the term "diversity" and the biodiversity issue, because they are often confused. The Committee of Scientists (1979) suggested that in the National Forest Management Act (NFMA) Congress intended the ". . . term diversity to refer to biological variety rather than any of the quantitative expressions now found in the biological literature." Second, although there is a distinction between the two, some diversity measures will be useful in addressing specific biodiversity questions. One of the major conclusions from a Southeastern Station/SARRMC conference on diversity related to the NFMA was, "Diversity indices must be used as an analytical tool and not used to define diversity" (Cooley and Cooley 1984).

Biodiversity is often erroneously understood to mean species diversity within stands or communities, probably because that has been the most common use of the term "diversity" in the literature. Compounding the misunderstanding is MacArthur's (1955) once widely accepted theory that community stability is related to diversity. Much ecological evidence has since been collected suggesting that the relationship of stability to diversity is unpredictable (Kikkawa 1986; Kimmins 1987; May 1974; Watt 1968). Ecologists no longer generally assume that high species diversity ensures stability (Wilson 1989).

According to Kimmins (1987), "Diversity can refer to all organisms in the community, but it is more frequently used to refer to one type or group of organism. Thus we can talk about the diversity of vascular plants, of birds, of mammals, and of the soil fauna." Diversity is a simple general concept that grows rapidly complex with attempts at measurement and comparison. The simplest characterization of diversity—a species enumeration—has very limited usefulness (Kimmins 1987). There is a generally recognized need to include some measure of how evenly importance or abundance is distributed among the different species. Pielou (1969) maintained that diversity is essentially ". . . a single statistic in which the number of species and evenness are confounded." Peet (1974) demonstrated that several different concepts have been grouped under the title of diversity and that many different indices have been legitimately used. He concluded that (1) species richness, or the number of species in a community, and (2) equitability, or the evenness with which importance is distributed among species, are particularly pertinent. The most widely used indices of diversity combine species richness and evenness in a single quantitative expression. Specific indices will not be discussed here, but it should be noted that indices differ in significant ways. Some indices are strongly affected by sample size and others are not. Some indices are more sensitive to the rarer species, whereas others are more affected by the dominant species in a sample. Such considerations will obviously be critical in addressing specific biodiversity problems. It should also be recognized that some diversity indices are inherently subject to manipulation, misuse, or misinterpretation. Since calculation for the most popular indices involves evenness, as well as richness, the index value can be increased by reducing the abundance of the most prevalent species without changing the abundance of the rarer species.

Another critical consideration is the trait selected to represent the importance or abundance component of diversity indices. The simplest is number of individuals. However, is it meaningful to compare trees with herbaceous plants on this basis? or mature trees with seedlings? Should two birds of the same sex that are past breeding age carry the same mathematical weight as a nesting pair? Such considerations must be addressed in the context of specific problems or questions. In many cases it has been useful to employ traits such as cover, biomass, or basal area – rather than number of individuals – to represent the degree to which a community is occupied (i.e., importance or abundance) by different species.

The influence of structural diversity can be more ecologically significant than species diversity. Structural diversity is usually defined by applying a diversity index to some measure of biomass occurring at different vertical strata in a community. The importance of vegetative structure was demonstrated by Robert and John MacArthur (1961), who found the richness of bird species positively related to the vertical distribution of foliage.

Diversity can be viewed in several contexts and on different geographic scales. The preceding discussion applies primarily to species within individual communities (which can vary tremendously in size). This form is referred to as "alpha diversity." The term "beta diversity" has been defined as ". . . the degree of change in (species) diversity along a transect or between habitats," (Magurran 1988) or as "the variation in species composition between two adjacent communities on an environmental gradient . . . " (Kimmins 1987). There are specific indices for expressing beta diversity. Alpha and beta diversity are the two categories most often found in the literature. However, the diversity of some larger unit, such as an island or landscape, is known as "gamma diversity," and "epsilon" or regional diversity is ". . . the total diversity of a group of areas of gamma diversity" (Magurran 1988). The indices commonly applied to alpha diversity are also used at different scales. Rather than being applied to species as elements of communities, they are sometimes applied to communities as elements of landscapes (Elliott 1990). The same indices could be applied within species with genes, other genetic units, or phenotypic traits as elements.

From the preceding definitions and the issue statement, it should be apparent that diversity within or among communities is not synonymous with biodiversity. **The biodiversity concern is not about the local diversity of flora and fauna, but whether species or ecosystems are threatened.** In the context of the issue, a reduction in species or community diversity would significantly impact biodiversity only if that reduction brought the local population of one or more species below a viable level by affecting factors such as numbers, sex and age structure, and the genetic base (the variety of genes within a population). The desirability of high versus low species or community diversity depends on specific biological requirements. For instance, increases in woody species diversity would threaten Kirtland's warbler, the red-cockaded woodpecker, and the northern spotted owl, thereby threatening biological diversity (Norse and others 1986). These species are all habitat specialists that require a fairly uniform environment. Conversely, in Maine the American woodcock requires forest openings, alder swamps, and 15- to 30-year-old deciduous stands within a limited radius (Sepik and others 1981), so diversity among communities is critical to this habitat specialist. Habitat generalists, such as the white-tailed deer, can thrive in a number of different environments, some of which may be uniform and others diverse (Hunter 1990).

Priorities and Approaches for Biodiversity Research

The fundamental goal of maintaining viable populations to perpetuate genes, species, and ecological communities clearly implies certain priorities for biodiversity research and management. Any cogent, comprehensive biodiversity program must include threatened and endangered species as the first priority. More difficult decisions about research direction lie beyond the obvious priority of threatened and endangered species. High priority also must be given to approaches that are more holistic than the piecemeal crisis efforts into which threatened and endangered species force the scientific community.

The second level of priority would logically be species most likely to become threatened or endangered. Continuing in the current mode of operation would require research at this priority level to be guided by a comprehensive inventory of species and their status. However, this task is so large that thousands of species would become extinct before their status was determined. Furthermore, working with individual species ad infinitum focuses on symptoms rather than the basic problem. One of the major threats to biological diversity is declining habitat area generally and reduced size of contiguous habitat (habitat fragmentation) in particular (Soulé and Kohm 1989). According to Norse and others (1986), "Of the various threats to biological diversity on National Forest lands, habitat fragmentation is perhaps the most serious." It follows that with limited resources the only truly successful research and management programs for biodiversity will be oriented primarily towards maintaining an array of representative ecosystems. Blockstein (1990) maintains that ". . . preservation of multiple examples of all the natural communities occurring within the United States should be a national goal." The assumption is that maintaining communities or ecosystems automatically ensures perpetuation of a large proportion of the component species. However, the validity of this approach depends on the selection and application of community classification systems. Most systems are based on a small number of dominant species: the mere occurrence of those species at any age or stage of community development does not ensure that all potential component species and functions exist. The Nature Conservancy uses the term "coarse filter" for the community approach and "fine filter" for the individual species approach (Noss 1987). Both approaches are necessary because ecosystem classification schemes are not comprehensive enough to encompass every species (Hunter 1990). Also, Pulliam (1988) argues convincingly that the perpetuation of some species depends on reproduction in source areas to replace mortality in certain "sink" habitats and that this dynamic relationship is evolutionarily stable.

Given the preceding priorities and limitations, a coordinated program of biodiversity research could be structured under three general subject areas: (1) threatened, endangered, and sensitive species; (2) restoration of missing, underrepresented, or declining forest communities; and (3) general principles and approaches for ecosystem restoration and perpetuation. **These areas of research are not mutually exclusive. In fact, they must overlap with a high degree of coordination to be efficient and effective.** The necessary overlap should be kept in mind in reviewing the following descriptions:

Threatened, Endangered, and Sensitive Species(TES)

This area is already defined by current and planned work with, for example, the red-cockaded woodpecker, neotropical migrant passerines, and nonmigratory avian species. A primary focus on individual species is what distinguishes TES from other subject areas in the suggested structure.

Restoration of Missing, Underrepresented, and Declining Forest Communities

This work is distinguished by a focus on specific target communities. It includes identifying and prioritizing them; defining their critical attributes (minimum viable area, species composition, structure, function, interior species, keystone species, indicator species); locating potential sites and evaluating site suitability; and developing alternatives for restoration and perpetuation.

For each community the types and levels of management that are compatible with the perpetuation of the community will have to be determined. Two additional areas of research will apply to each community: (1) the degree to which small islands or fragments of the community can substitute for larger contiguous areas if the fragments are connected by corridors of similar type, and (2) determining minimum viable populations for certain critical component species. Questions associated with the first area relate to size, shape and proximity of fragments and to corridor characteristics in the context of organisms that will move along the corridors (Hunter 1990). Maintenance of viable populations was suggested earlier as a criterion for judging success of biodiversity programs. In fact, determining what constitutes a viable population will be a major research undertaking for many species. Although there are general rules of thumb, such as 50 breeding individuals for the short term and 500 for indefinite survival (Frankel and Soulé 1981), more recent work suggests that minimum viable populations could range from hundreds to millions, depending on the organism (Soulé 1987). Many factors influence population viability (Shaffer 1981), and population viability analysis is emerging as a recognized field of work (Hunter 1990). In attempting to estimate the minimum viable population, genetic composition is often more important than pure numbers (Soulé and Kolm 1989).

There is a potential need for community restoration in all three physiographic provinces of the Southeast. General examples of candidate target communities are the longleaf pine-wiregrass on the Coastal Plain, various upland hardwood communities in the Piedmont and Mountains, and specific wetland communities in all three provinces.

General Principles and Approaches for Ecosystem Restoration and Perpetuation

Research in this area is distinguished by problems and solutions that generalize across communities. Included are development of methods for locating and evaluating potential sites and for introducing missing species as well as determination of the potential role of human disturbances (such as harvesting and burning) in changes in species composition. Other questions addressed under this heading would be the general function of coarse woody debris in southeastern communities; the degree to which younger communities can be structured to mimic old growth; the importance of structural diversity in southeastern communities; the degree to which features such as roads, powerlines, trails, and firelines fragment communities by creating barriers to animal and plant movement; and approaches for population viability analysis. Associated with these questions should be landscape-level investigations into the frequency with which species are perpetuated by the source-sink habitat relationships discussed by Pulliam (1988).

Specific problems under all three general subject areas must be addressed in different ways and on different scales than traditional investigations. There are obvious limitations on where and by whom effective research on some biodiversity questions can be conducted. Certain questions will require landscape-level investigations with (1) firm control over human perturbations; (2) security for costly field instrumentation; (3) a continuing level of multidisciplinary research; and, perhaps most importantly, (4) landowner commitment, often for very long periods. These criteria are so restrictive that any organizations with the capacity and willingness to meet them could attain a global reputation in biodiversity research.

Selected References

Blockstein, David E. 1990. Toward a federal plan for biological diversity. Journal of Forestry 88(3):15-19.

Committee of Scientists. 1979. Final report. Federal Register 44(88):26599-26657.

Cooley, James L.; Cooley, June H., eds. 1984. Natural diversity in forest ecosystems. Proceedings of the workshop; 1982 November 29 - December 1; Athens, GA. Athens, GA: University of Georgia, Institute of Ecology: page ii. 290 pp.

Elliott, Catherine A. 1990. Diversity indices. In: Hunter, Malcolm L., Jr. Wildlife, forests, and forestry: principles of managing forests for biological diversity. Englewood Cliffs, NJ: Prentice Hall, Inc: 297-302.

Frankel, O.H.; Soulé, M.E. 1981. Conservation and evolution. Cambridge, Great Britain: Cambridge University Press. 327 pp.

Harris, Larry D. 1984. The fragmented forest: island biogeography theory and the preservation of biotic diversity. Chicago: University of Chicago Press. 211 pp.

Hunter, Malcolm L., Jr. 1990. Wildlife, forests, and forestry: principles of managing forests for biological diversity. Englewood Cliffs, NJ: Prentice-Hall. 370 pp.

Kikkawa, J. 1986. Complexity, diversity, and stability. In: Kikkawa, J.; Anderson, D.J., eds. 1986. Community ecology: pattern and process. Melbourne, Australia: Blackwell: 41-62.

Kimmins, J.P. 1987. Forest ecology. New York: Macmillan Publishing Company. 531 pp.

Landres, P.B.; Verner, J.; Thomas, J.W. 1988. Ecological uses of vertebrate indicator species: a critique. Conservation Biology 2:316:328.

Lubchenco, J.; Olson, A.M.; Brubaker, L.B. [and others]. 1991. The sustainable biosphere initiative: an ecological research agenda. Ecology 72:371-412.

MacArthur, R.H. 1955. Fluctuations of animal populations, and a measure of community stability. Ecology 36:533-536.

MacArthur, R.H.; MacArthur, J.W. 1961. On bird species diversity. Ecology 42:594-598.

Magurran, Anne E. 1988. Ecological diversity and its measurement. Princeton, NJ: Princeton University Press, 179 pp.

May, R.M. 1974. Stability and complexity in model ecosystems. 2d ed. Princeton, NJ: Princeton University Press. 265 pp.

National Research Council Committee on Forestry Research. 1990. Forestry research: a mandate for change. Washington, DC: National Academy of Sciences. 84 pp.

Norse, Elliott A., Rosenbaum, Kenneth L., Wilcove, David S. [and others]. 1986. Conserving biological diversity in our National Forests. Washington, DC: The Wilderness Society. 116 pp.

Noss, R.F. 1983. A regional landscape approach to maintain diversity. BioScience 33:700-706.

Noss, R.F. 1987. From plant communities to landscapes in conservation inventories: a look at the Nature Conservancy (USA). Biological Conservation 41:11-37.

Noss, R.F. 1990. Indicators for monitoring biological diversity: a hierarchical approach. Conservation Biology 4:355-364.

Office of Technology Assessment. 1987. Technologies to maintain biological diversity. Summary. Washington, DC: U.S. Government Printing Office. Stock No. 052-003-01058-5.

Peet, Robert K. 1974. The measurement of species diversity. Annual Review of Ecology and Systematics 5:285-307.

Pielou, E.C. 1969. An introduction to mathematical ecology. New York: Wiley-Interscience. 286 pp.

Probst, John R.; Crow, Thomas R. 1991. Integrating biological diversity and resource management. Journal of Forestry 89(2):12-17.

Pulliam, H. Ronald. 1988. Sources, sinks, and population regulation. The American Naturalist 132(5):652-661.

Reid, Walter V.; Miller, Kenton R. 1989. Keeping options alive: the scientific basis for conserving biodiversity. Washington, DC: World Resources Institute. 111 pp.

Salwasser, Hal. 1990. Gaining perspective: forestry for the future. Journal of Forestry 88(11):32-38.

Sepik, G.F.; Owen, R.B., Jr.; Coulter, M.W. 1981. A landowner's guide to woodcock management in the Northeast. Misc. Rep. 253. Orono, ME: Maine Agricultural Experiment Station.

Shaffer, M.L. 1981. Minimum population sizes for species conservation. BioScience 31(2):131-134.

Soulé, Michael E., ed. 1986. Conservation biology: the science of scarcity and diversity. Sunderland, MA: Sinauer Associates. 584 pp.

Soulé, M.E., ed. 1987. Viable populations for conservation. Cambridge, Great Britain: Cambridge University Press. 189 pp.

Soulé, Michael E.; Kohm, Kathryn A., eds. 1989. Research priorities for conservation biology. Washington, DC: Island Press. 97 pp.

Temple, S.A. 1977. Plant-animal mutualism: coevolution with dodo leads to near extinction of plant. Science 197:885-886.

Watt, K.E.F. 1968. Ecology and resource management: a quantitative approach. New York: McGraw-Hill. 450 pp.

Whittaker, Robert H. 1975. Communities and ecosystems. 2d ed. New York: Macmillan. 385 pp.

Wilcox, B.A.; Murphy, D.D. 1985. Conservation strategy: the effects of fragmentation on extinction. American Naturalist 125:879-887.

Wilson, Edward O. 1985. The biological diversity crisis. BioScience 35:700-706.

Wilson, Edward O. 1989. Threats to biodiversity. Scientific American 261(3):108-116.

McMinn, James W. 1991. Biological diversity research: an analysis. Gen. Tech. Rep. SE-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 7 pp.

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