is noteworthy that all computing machines use temporal pulsing. A possible third role is suggested in some of the theories mentioned above: the use of phase relationships of temporal pulses to handle information and control the growth and development of cells and organisms (*5*).

In some sense, structure—functional structure in a teleological sense, as opposed to mere crystalline shape—must also be considered a stage, possibly intermediate between crystallinity and information strings, in the hierarchy of broken symmetries.

To pile speculation on speculation, I would say that the next stage could be hierarchy or specialization of function, or both. At some point we have to stop talking about decreasing symmetry and start calling it increasing complication. Thus, with increasing complication at each stage, we go on up the hierarchy of the sciences. We expect to encounter fascinating and, I believe, very fundamental questions at each stage in fitting together less complicated pieces into the more complicated system and understanding the basically new types of behavior which can result.

There may well be no useful parallel to be drawn between the way in which complexity appears in the simplest cases of many-body theory and chemistry and the way it appears in the truly complex cultural and biological ones, except perhaps to say that, in general, the relationship between the system and its parts is intellectually a one-way street. Synthesis is expected to be all but impossible; analysis, on the other hand, may be not only possible but fruitful in all kinds of ways: Without an understanding of the broken symmetry in superconductivity, for instance, Josephson would probably not have discovered his effect. [Another name for the Josephson effect is "macroscopic quantum-interference phenomena": interference effects observed between macroscopic wave functions of electrons in superconductors, or of helium atoms in superfluid liquid helium. These phenomena have already enormously extended the accuracy of electromagnetic measurements, and can be expected to play a great role in future computers, among other possibilities, so that in the long run they may lead to some of the major technological achievements of this decade (*6*).] For another example, biology has certainly taken on a whole new aspect from the reduction of genetics to biochemistry and biophysics, which will have untold consequences. So it is not true, as a recent article would have it (*7*), that we each should "cultivate our own valley, and not attempt to build roads over the mountain ranges . . . between the sciences." Rather, we should recognize that such roads, while often the quickest shortcut to another part of our own science, are not visible from the viewpoint of one science alone.

The arrogance of the particle physicist and his intensive research may be behind us (the discoverer of the positron said "the rest is chemistry"), but we have yet to recover from that of some molecular biologists, who seem determined to try to reduce everything about the human organism to "only" chemistry, from the common cold and all mental disease to the religious instinct. Surely there are more levels of organization between human ethology and DNA than there are between DNA and quantum electrodynamics, and each level can require a whole new conceptual structure.

In closing, I offer two examples from economics of what I hope to have said. Marx said that quantitative differences become qualitative ones, but a dialogue in Paris in the 1920's sums it up even more clearly:

FITZGERALD: The rich are different from us.

HEMINGWAY: Yes, they have more money.

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Natural Areas

While harboring valuable species, natural areas also serve as bench marks in evaluating landscape change.

William H. Moir

"The sheep destroy young trees and when the old ones die no forest will be left"; thus H. C. Cowles described the situation after his epochal study in 1899 of plant succession on the dunes of Lake Michigan (*1*). Cowles knew well how the heavy hand of man could accelerate changes in vegetation, often in undesirable directions. He and his colleague V. E. Shelford had seen the expanding city of Gary threaten ever more of the "quiet but varied beauty" of the dunes and wooded hills (*2*). Man's destruction of the natural landscape appeared so widespread and pervasive that in 1917 the newly organized Ecological Society of America appointed Shelford the chairman of a committee to find out what remained of wild, natural America and to promote the idea of a system of natural preserves (*3*).

Some 50 years later, President Nixon repeated the need—which had become urgent—of preserving the natural environment (*4*):

> I am submitting to Congress several bills that will be part of a comprehensive effort to preserve our natural environment and to provide more open spaces and parks in urban areas where today they are often so scarce.

Those 50 years had seen Gary fuse with Calumet City, Hammond, Whiting, and East Chicago to become an environmental nightmare. To be sure, a vestige of the extensive dunes still existed, but Lake Michigan itself was becoming eutrophic. Often the sky was a miasma, with summer rains leaching sulfur dioxide from the air and killing many plants. Ducks pausing at some last-remaining marsh of their famous ancestral flyway had high levels of DDT or lead in their bodies.

Natural areas play a crucial role in the rapidly changing landscape. Most important, perhaps, is that they serve as bench marks for assessing the extent of man's impact upon diverse land, lake, river, estuary, and coastal environments. In this article, I define natural areas, as they are currently envisioned by many scientists; examine some of the forces that have advanced or opposed natural areas as a basis for policies of land use; and discuss what uses can be made (*5*) of the unique kind of scientific information they contain.

Characteristics of Natural Areas

The characteristics of natural areas can be extracted from various policy statements and definitions that are typical at national, state, and local levels.

The U.S. International Biological Program states (*6*):

> There is high scientific value in preserving samples of typical environments, both those relatively little disturbed by man, and those which he has materially modified. . . . Areas preserved for long-term scientific use provide natural laboratories for the study of ecosystems in all their complexity. . . . They can serve as check areas or yardsticks for the use, protection and management of comparable areas of land or water. . . . They are reservoirs of genetic materials which may one day prove to be of economic or medicinal value.

The government of the U.S.S.R. states (*7*):

> Reserves in the U.S.S.R. are scientific institutions removed from economic utilization and located over the most important geographical zones and landscapes, and destined for permanent and complex investigations on natural resources under undisturbed conditions.

The Illinois Nature Preserves System Act states (*8*) that a nature preserve is any area retaining "to some degree its primeval character" or has "unusual flora, fauna, geological, or archaeological features of scientific or educational value" and is set aside "for scientific research, education, esthetic enjoyment and providing habitat for plant and animal species and communities and other natural objects."

The Society of American Foresters (SAF) states (*9*) that natural areas are lands "set aside to preserve permanently in unmodified condition a representative unit of virgin growth" from all important forest and range types, or any area containing plant communities that have special or unique characteristics of scientific interest or importance, whether on federal, state, municipal, institutional, or private lands.

From these statements, there emerge six basic characteristics of a natural area. The first three involve recognition, the fourth involves management, and the last two are statements of primary purpose.

1) Natural areas are part of a system. Members of the system are "samples of typical environments" or ecosystems "in all their variety" from all "geographical zones and landscapes" or from all "forest and range types." At state or national levels, natural areas become part of a "comprehensive effort" to preserve examples of the natural environment.

2) Minimum disturbance by man is an essential feature. Natural areas are "unmodified," of "primeval character," relatively little "disturbed" by man, and consist of "natural objects" in their "natural condition."

3) Natural areas are based on ecological criteria. Emphasis is given to "habitats," "communities," floristic or faunistic "types" or "associations," and "ecosystems in all their complexity."

4) Members of the natural area system are assured preservation and permanency to the greatest possible degree (*10*). They are "set aside," "removed from economic utilization," and any usage should be, as far as possible, nondestructive. In some states, "development" is expressly prohibited by statute.

5) These withdrawals into protective status are for scientific and educational purposes. Natural areas are laboratories for complex investigations. In particular, they serve as important bench marks. General public use in some natural areas may be prohibited, discouraged, or given secondary importance.

6) Natural areas harbor genetic stock of possible value to society in agricultural, silviculture, mariculture, medicine, and other areas, including esthetics. Definitions may refer to "unusual" plants and animals; the scientist can perceive ecotypes whose perpetuation in natural areas may serve important contemporary or future genetic purposes.

Natural areas with these six characteristics occur in a wide variety of jurisdictions. Natural parks, wilderness areas, wildlife refuges, wild rivers, abandoned lots, coastal segments, or the "back forty" may all have qualities of a natural area. Ownership may be public or private. Some areas, in or near oceans, for example, may be of international concern; others are primarily of local interest. However, the growing awareness of environmental deterioration during the 1960's created alliances between ecologists interested in the preservation of natural areas and other groups struggling with the primarily urban problems of crowding, open space, outdoor beauty, environmental education, and the quality of the immediate, daily surroundings of the city dweller. Diverse public interests, professional societies, and private groups and institutions have explicit concerns about natural areas (*11*). The U.S. Forest Service was one of the first federal agencies to develop a program for natural areas; a look at the forces that shaped the growth of their program is instructive.

Natural Areas and the Forest Service

The Forest Service had no official policy on natural areas in 1922; the primary purposes of forests on public lands were sustained timber production and the "development" of forage, water, recreation, and other resources. Most forests in their natural state were regarded as decadent and unproductive. However, the desirability of withdrawing specific forest areas from utilization had been suggested by officials who feared the disappearance of all primeval stands. It was proposed that some "vestigial units" could be held as references and guides for future forest studies in each of the typical types of timber (*12*). Research foresters realized the value of undisturbed, natural forest stands as controls for experimental studies. Their techniques included the use of exclosures to keep grazing livestock or other disturbances from certain areas (*13*). The idea of comparing treated and untreated areas was soon a common field practice.

Preservation of certain Forest Service lands was strongly advocated for other purposes as well. In 1909, Aldo

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Leopold joined the service's New Mexico district. Within a few years, he had become influential in promoting the values of wilderness for wildlife management, recreation, and scientific research. His ideas became an effective counterforce to the utilitarian conservation theories of Gifford Pinchot (*14*). In 1920, his colleagues received authorization to keep the Trapper Lake area in Colorado in "primitive" condition; in 1924, Leopold saw the establishment of the 574,000-acre Gila Wilderness in New Mexico. Wilderness, primitive, and natural areas were not differentiated, but the concept of protective withdrawals had been begun, and it took hold (*15*). The Multiple Use Act of 1897 and numerous subsequent acts to 1960 had made provisions for various uses of public forest lands. In 1929, the "L-20" regulations were issued, setting aside special forest lands for recreation. A 4500-acre ponderosa pine forest in Arizona, withdrawn from timber or forage production in 1927, was the first natural area set aside primarily for scientific study. By 1940, the Forest Service had designated 31 such areas on federally administered forest lands. In 1941, Leopold, who had become a wildlife professor at the University of Wisconsin, wrote that "a science of land health needs, first of all, a base-datum of normality, a picture of how healthy land maintains itself as an organism" (*16*). The Forest Service no longer needed this exhortation—their natural area system was firmly established.

In 1947, the SAF organized its committee on natural areas to promote establishment of natural areas on both public and private lands and to encourage use of these areas by the scientific and educational community (*17*). The committee was directed to develop and maintain standards of conditions and quality governing the selection of natural areas and to set forth principles for their protection and management. The SAF did not establish official Forest Service policy on natural areas, but members of the natural area committee, including its various chairmen from 1947 on, were employees of the service. Early accomplishments of the SAF committee were related to the establishment of natural areas on state, institutional, and private lands, often in cooperation with universities, the Nature Conservancy, and other groups. Until recently, the committee based its evaluation of what natural areas were needed upon concepts of forest cover types, which emphasized dominant timber growth and not necessarily the total assemblage of plants and animals (*18*). This conceptual difference between foresters and ecologists often produced difficulties in establishing natural areas.

In the 1960's, a marked upsurge of interest in natural areas on Forest Service lands reflected heightened national concern about the rate at which both rural and urban man was "fouling the nest." The natural landscape was disappearing at an alarming rate. A long list of conservation legislation included the Wilderness Act of 1964 and the Land and Water Conservation Fund Act of 1964. Rachael Carson had alerted the nation to the persistent and pervasive nature of our poisoning programs. President Johnson affirmed the right of every American "to enjoy plants and animals in their natural habitats—and the duty not to eliminate them from the face of the earth" (*19*, p. 203). The President's Scientific Advisory Committee on Environmental Pollution submitted a long list of recommendations, which included the following (*20*).

1) Funds should be made available to acquire title to important coastal marshes, lagoons, and estuaries. "Critically important protection against pollution can be combined with preservation of some natural areas" (*20*, p. 8).

2) The federal government should undertake a "new program for gathering and making information available about effects of environmental changes" on federal lands (*20*, p. 9).

3) Efforts should be made to establish scientific bases for standards of environmental quality.

4) A program should be established to collect data on natural populations in relatively unpolluted areas. These data would provide an important bench mark for assessing the conditions of the environment.

The thrust of these recommendations was not lost upon the secretaries of Agriculture and the Interior. A joint statement by Freeman and Udall pointed out that "research natural areas are important as baselines against which man-caused changes can be measured" (*21*). In May 1966, the *Forest Service Manual* stated that the service "will cooperate with other public agencies and such private and professional organizations as the Nature Conservancy, Society of American Foresters, American Society of Range Management, and Ecological Society of America, to establish and maintain an adequate number and variety of research natural areas" (*22*). A month later, the chief of the Forest Service advised his regional foresters that, in the face of growing air and water pollution and general environmental deterioration in the United States, the service should be in a position to furnish baseline ecological information from their system of natural areas. By this time, there were about 70 natural areas in the total national forest domain, but the protection afforded some of them was lax. Directors of experiment stations were urged to set aside additional areas to make this system more comprehensive. With encouragement from the SAF committee on natural areas, the Forest Service broadened its concept of natural areas to include *any* natural community having special or unique characteristics and it emphasized the necessity of instituting research on these lands. The chief of the Forest Service stated that the service had an obligation to see that a well-rounded system of natural areas was available for future scientific and educational research. By 1968, the service was recommending the establishment of natural areas for every significant plant community within its jurisdiction, as well as the establishment of several natural area preserves for the more geographically extensive forest and range types (*22*).

Establishment of Natural Area Preserves

In most cases, the first indication that an area qualifies as a natural area comes from biologists in governmental research agencies or at local schools and universities. Criteria for the recognition of natural areas have been formalized by the International Biological Program and other groups (*23*), but judgments on the degree to which any given area meets particular criteria often vary among decision-makers. Classification of natural area systems was originally based upon ecological concepts (*3*). Considerable leeway was given ecologists within each region, or "biotic province," to identify major types of vegetation and to judge the degree to which specific areas containing these types qualified for preservation. Proposals for establishing a natural area were then submitted to agencies or individuals managing the particular area. The basic decision involved was whether the proposed natural area deserved preservation and permanent protection for primarily scientific and educational purposes. This is also the critical decision today. If an area happens to be on national forest land, proposals to establish it as a natural area are sent to the regional natural area committee (*24*). Establishment depends heavily upon corroboration by local foresters that the basic characteristics of the natural area concept are present. There are likely to be conflicting viewpoints on at least some of the merits of the natural area in question, especially if ecological or floristic and faunistic considerations do not accord with silvicultural or timber harvest plans (*24*).

The major difficulty in establishing natural areas usually concerns the contradictory goals of utilization and preservation. Opposition to protective withdrawal of public lands is usually voiced by timber, recreation, and mining interests. Many foresters and other managers of public land believe that conservation requires development. They emphasize the right of the present generation to the fullest necessary use of the resources of the area and oppose withdrawal for more narrow purposes of science and education (*14, 25*). This is particularly true when scientific or educational institutions are not in sight. Who, after all, is going to study something way out in the boondocks? The value of a natural area increases considerably, however, after developmental interests have so blanketed a region that only minuscule fragments remain to be preserved as bench marks. The Wildcat Mountain Research Natural Area in Oregon features some highly productive noble fir forests of prime timber quality and easy logging access. So little of this remains in protective status that arguments for withdrawal outweighed arguments for keeping it open to timber harvest. Indeed, the threat of total extinction of a natural ecosystem is often the argument that tips the scales in favor of preservation (*26*).

Natural Areas as Environmental Monitoring Systems

The federal government spends millions of dollars annually for equipment to monitor various aspects of the environment (*27*). Often the data cannot be assessed in terms of human health. It is a difficult statistical task to find short- or long-term relations between outputs from sensing devices and complex physiological and genetic systems. Natural areas are a different kind of environmental monitoring system. The diverse plant and animal components integrate both short- and long-term relations among the environmental factors that are essential to their physiological maintenance from generation to generation. The health and vigor of these populations and the continuance, or unbalance, of ecological assemblages can serve as a warning system for man. If the pelicans die, what does this forebode for man, the fish eater? If a lichen disappears from its natural area habitat in Connecticut, what does this indicate about the air quality there? What are the implications of the kind of resource husbandry that permits the last population of productive cork-bark firs to be destroyed in their insular habitat in southern New Mexico?

The idea of natural areas as environmental monitoring systems stems from their use as controls or bench marks (*28*). Ecosystems in their more or less natural state are measured for predictive purposes against similar ecosystems that have been altered by man. The ecological concepts that are important for predictive purposes are succession and environmental drift (*29, 30*). Both processes involve change in the relative proportions between species of the ecosystem; both result from changes in the causative factors of the environment. If patterns of succession are known, the ecologist can predict, after a disturbance or environmental change, certain sequences of population response, up to and including a terminal, steady-state ecosystem. These predictions assume certain known conditions about the new environment within which succession takens place. If causative factors of the new environment are erratic, uncertain, or beyond the experience of biologists (as, say, in the gradual buildup of lead in the ecosystem), then predictions are less exact and are based primarily upon biological generalities (for example, increasing concentrations of pollutants along trophic chains). It is useful to distinguish two basic ways in which man tampers with the landscape. He may create environmental changes that were also common in the evolution of the ecosystem. Prairie or forest fires are good examples. In such cases, the transient buildup of high temperatures or smoke and carbon dioxide in the atmosphere cannot be regarded as pollution, insofar as such events would have long since eliminated species not adapted to such events. On the other hand, man also imposes upon ecosystems environmental changes that are new in terms of the evolution of the component populations. The sustained, high levels of sulfur dioxide in the atmosphere around industrial regions or the cycling of mercury in aquatic ecosystems are new factors of natural selection (*31*). The dynamics of ecosystems within natural areas can provide essential perspectives on the degree and possible consequences of changes in the environment caused by either kind of interference.

Natural areas furnish baseline data on the environment from the time measurements are begun, not from the time an area is established. We may never know what plants grew on the prairies of the Chicago area 200 years ago, but the Chiwaukee Prairie natural area, near Kenosha, Wisconsin, can provide scientists with numerous contemporary facts from which they can determine norms of biogeochemical cycling, productivity, species tolerances to pollutant buildup, or whatever. That this hydric prairie has already been affected in unknown ways by accelerated changes in the regional environment is immaterial; scientists can still acquire baseline data from the time a measurement program is initiated, and this data will become increasingly significant in the future. Since natural areas are set aside as preserves, repeated measurements at some future date can be assured and can provide evidence of trends when compared with baseline measurements.

Surveillance of the national or global environment is still very much an art. There is no clear definition of environmental quality control; of measures of deterioration of air, soil, water, or vegetation properties; of sampling standards for trends and patterns of pollutant concentrations; or of what constitutes the best buy in funding to determine the effectiveness of environmental quality programs (*32*). A system of natural areas dispersed throughout a political, geographical, or biological region can contribute to these measurement goals without particularly great expense. Natural areas require little or no maintenance (*10, 30*), and sampling stations within such areas can yield data on the surrounding environment, data whose analysis and interpretation is highly correlated with biological responses. This is, in fact, one of the main objectives of the International Biological Program and of its U.S. Analysis of Ecosystems, which is studying a variety of biomes (*33*). A greatly augmented, purposeful, national and global natural area system can provide an invaluable biological basis for measuring man's impact, and his future security, on this planet. At local levels, each natural area with its biotic reserves can give insights into the quality of environment as a whole, the kind of environments we would like to establish, modify, or extend, and policy and management opportunities to achieve these goals (*34*).

Summary

Natural areas are large or small segments of a regional landscape or seascape where present influences or effects of man's activities are minimal. The value of these areas for scientific and educational study often exceeds the commerical or economic value of the natural resources they harbor and warrants their long-term preservation and protection. Their scientific and educational value increases tremendously in regions where disturbance has been pervasive. The complex ecosystems of natural areas are generally more stable than ecosystems that have been drastically altered by man, since the latter may achieve stability only at the cost of large energy supplements. The degree to which man has impaired the natural, self-repairing capability of land or sea can be measured by reference to natural areas.

Diverse populations comprising natural area ecosystems are maintained with various degrees of vigor, depending on their physiological adaptations to a multitude of environmental factors. Natural areas can therefore be used to monitor the environment, thereby alerting man to deleterious changes. When used as sampling stations for environmental surveillance, natural areas aid the interpretation of possible biological consequences of pollutant buildup. They also provide comparative data on yields and productivity from managed or altered ecosystems. Because of these and other perspectives that natural areas provide (*5*), their protection and permanence should be given a high priority in policies of land use.

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