Chicago-Kent Law Review

Volume 69
Issue 4 *Symposium on the Ecology and the Law*

Article 4

June 1994

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THE DANCE OF NATURE: NEW CONCEPTS IN ECOLOGY

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INTRODUCTION

Ecology has changed. It is no longer an esoteric subdiscipline of biology; rather, it is truer to the meaning of its root word "oikos," which means "house" or "place to live." The science of ecology, as it is practiced today, is the study of our species' dwelling place, the planet Earth.[1] Modern ecologists examine the interrelationships between organisms (including humans) and all aspects of their environment (including physical, chemical, and biological aspects).

The purpose of this Paper is to discuss current and emerging concepts in ecology and how the application of these concepts could alter our approach to environmental management, regulation, and legislation.[2] This Paper identifies five current ecological concepts that are relevant to the field of environmental law. This list has been extracted and modified from a much longer list of "great ideas in ecology for the 1990s" developed by Gene Odum, who developed the list as a set of concepts that should be taught to students in an environmental literacy course.[3] The five ecological concepts discussed here offer insight into how best to regulate human activities and manage our biosphere to leave a healthier planet to future generations.

I. NATURAL SYSTEMS ARE OPEN AND CONTINUOUSLY CHANGING; THEY ARE NOT AT EQUILIBRIUM.

The classical paradigm in ecology conceives of an ideal ecosystem that is either at equilibrium, stable, or moving toward stability. In 1935, A.G. Tansley first defined the term "ecosystem" and wrote: "In an ecosystem the organisms and the inorganic factors alike are *com-*

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1. For a description of the research agenda for ecology in this decade, see Jane Lubchenco et al., *The Sustainable Biosphere Initiative: An Ecological Research Agenda,* 72 ECOLOGY 371 (1991).

2. For further discussion of the water resource management implications of these ideas, see Judy L. Meyer, *Changing Concepts of System Management, in* SUSTAINING OUR WATER RESOURCES (Water Science and Technology Board ed. 1993).

3. Eugene P. Odum, *Great Ideas In Ecology for the 1990s,* 42 BIOSCIENCE 542 (1992).

ponents which are in relatively stable dynamic equilibrium."[4] Raymond Lindeman, who developed the concept of trophic levels in ecology, had a similar view of the stability of natural systems: "[S]uccession is the process of development in an ecosystem . . . towards a relatively stable condition of equilibrium."[5] These early ecological thinkers conceived of an ideal system that was stable, and they viewed nature as striving to achieve that ideal. In the field of plant ecology, individuals sought to identify the stable, self-perpetuating, climax community[6] in an area and the well-defined stages leading to that climax. In the field of theoretical ecology, mathematical modelers solved their equations for the equilibrium condition.

Empirical data in several disciplines of ecology did not necessarily fit this classical paradigm. Natural communities were found to have multiple persistent states rather than a local climax, and there were multiple successional pathways — that is, several ways of getting there.[7] Ecologists recognized that terrestrial and aquatic ecosystems in nature were frequently subjected to a wide range of disturbances including fires, windstorms, insect outbreaks, floods, and droughts.[8] These disturbances alter succession and influence the distribution and abundance of species in the ecosystem.

Paleoecological studies revealed directional changes in climate that also affect natural ecosystems.[9] For example, data from an Antarctic ice core show that over the last 20,000 years, there have been temperature changes on the order of six degrees Celsius.[10] Fossil records of vegetation indicate that the annual temperature in the northeastern United States has changed about five degrees Celsius in

4. A.G. Tansley, *The Use and Abuse of Vegetational Concepts and Terms,* 16 ECOLOGY 284, 306 (1935).

5. Raymond L. Lindeman, *The Trophic-Dynamic Aspect of Ecology,* 23 ECOLOGY 399 (1942).

6. Early plant ecologists coined the term "climax community" to refer to the terminal stage of ecological succession. For example, after changes in vegetation following abandonment of an agricultural field in the Southern Piedmont, the oak-hickory forest that eventually occupies the site would be considered the climax community. The climax community was considered to reflect the climatic and edaphic setting of the site and to be persistent, stable, and in equilibrium with its environment.

7. *See, e.g.,* Daniel B. Botkin & Matthew J. Sobel, *Stability in Time-Varying Ecosystems,* 109 AM. NATURALIST 625 (1975).

8. V.H. Resh et al., *The Role of Disturbance In Stream Ecology,* 7 J. OF THE N. AM. BENTHOLOGICAL SOC'Y 433-55 (1988); Peter S. White, *Pattern, Process, and Natural Disturbance In Vegetation,* 45 THE BOTANICAL REV. 229 (1979).

9. M.B. Davis, *Climatic Instability, Time Lags, and Community Disequilibrium, in* COMMUNITY ECOLOGY 269-84 (Diamond & T.J. Case eds., 1986).

10. C. Lorius et al., *The Ice-Core Record: Climate Sensitivity and Future Greenhouse Warming,* 347 NATURE 139 (1990).

the past 10,000 years.[11] Although this may seem like a small change, these kinds of climatic changes have a considerable impact on forest communities, where 10,000 years is only about fifty generations of the dominant species. The results of a forest growth simulation model illustrate this impact: there is a shift in dominance from sugar maple to red spruce with just a two degree Celsius change in temperature.[12] Because of the long generation time of trees, the species-specific response to climate, and the relatively slow migration rate of trees, there is not time for the forests to come into equilibrium with the climate, which is continuously changing. Discoveries like these have led to a paradigm shift in ecology.[13]

The contemporary paradigm recognizes that ecosystems are open and not necessarily in equilibrium.[14] It recognizes disturbance to be a natural and necessary part of ecosystems. It recognizes that systems are influenced by and can, in fact, be controlled by events occurring in neighboring or even distant ecosystems. The focus of the contemporary paradigm is on process rather than endpoint—on the trajectory of change rather than on the final endpoint.[15] It recognizes historical contingency: the state of the system today depends on what happened yesterday as well as decades ago.

These changes in ecological approaches to the natural world reflect changes in underlying philosophical concepts: from a view of a world in equilibrium (the balance of nature) to a view that recognizes change and chance as inherent features of nature.[16] Unfortunately, we have not yet developed and popularized an image to replace that of the "balance of nature." I suggest "the dance of nature" as an image that conveys a sense of change and movement in response to a myriad of influences, just as a modern dancer moves in response to a musical score.

In his book *Discordant Harmonies,* Dan Botkin traces these changes in world view that have influenced ecology as well as other sciences. He follows the development of scientific thought from a view of a divinely ordered, perfect, and unchanging nature, to a view

11. Davis, *supra* note 9.

12. *Id.*

13. Steward T.A. Pickett et al., *The New Paradigm in Ecology: Implications for Conservation Biology Above the Species Level, in* CONSERVATION BIOLOGY: THE THEORY AND PRACTICE OF NATURE CONSERVATION PRESERVATION AND MANAGEMENT 65 (Peggy L. Fiedler & Subodh K. Jain eds., 1992).

14. *Id.*

15. *Id.*

16. DANIEL B. BOTKIN, DISCORDANT HARMONIES: A NEW ECOLOGY FOR THE TWENTY-FIRST CENTURY (1990).

of nature as a machine operating at steady state, to the contemporary view that incorporates change as a natural and necessary part of the biosphere.[17]

The classical view of nature is of a system striving for equilibrium, which implies that systems will maintain themselves in balance if they are protected from human disturbance. This view results in a very different conservation and management strategy than the strategy that would result from the non-equilibrium paradigm. Botkin offers examples of the consequences of managing according to the classical paradigm in a world of change; one of those examples comes from New Jersey.[18] In 1955, The Hutcheson Memorial Forest was preserved as the last remaining old growth oak forest in central New Jersey. Because the forest was considered to be at climax and hence at equilibrium, no manipulation or disturbance of the forest was to be permitted. As a consequence, the forest today looks quite different than it did in 1955: the old oaks are reaching senescence, but there is little evidence of successful oak regeneration; sugar maple saplings are abundant, suggesting the future forest will be sugar maple, not oak; dogwood populations have been reduced by disease; gypsy moth defoliation and the presence of exotic species in the neighborhood led to invasion of the understory by light-loving imported herbs and shrubs. What went wrong?

It is now clear that the dominant species in this forest, like many others, requires periodic fire disturbance for regeneration and suppression of competitors, and in fact there is evidence of the occurrence of light fires about every decade prior to European occupation of the region. Thus, the conservation strategy of fire suppression that was developed based on a classical equilibrium paradigm failed to protect what the designers of the preserve valued most. Rather than simply protecting the endpoint, we need to preserve the processes that generate the desired result. Disturbance—in this case fire—is an essential part of the process.

Disturbance is also inevitable, and a recognition of this should inform our management strategy. Events, like hundred-year droughts or floods, will occur and will affect the ecosystem we are trying to manage or the species we are trying to conserve. Management plans that do not consider the consequences of these rare, inevitable, and potentially catastrophic events will not be successful in the longterm

17. *Id.*
18. *Id.*

preservation of landscape fragments or species, particularly if the area being preserved or the species population size is small.

Disturbance is a determining feature of aquatic ecosystems. When the disturbance regime of a river is altered—for example, by construction of a dam or by altering the seasonality of flows—the system changes.[19] This has happened below Glen Canyon Dam on the Colorado River.[20] The riparian zone has expanded and has been invaded by several exotic species because of stabilized flows that left a larger riparian area moist.[21] Native fishes are failing to reproduce because of the absence of large seasonal changes in water level, which previously had synchronized their breeding cycles.[22] The removal of the disturbance associated with water level fluctuations has altered the riverine ecosystem.

When a natural disturbance does occur, management based on the contemporary paradigm would allow the system to recover from the disturbance. This is currently a major issue in the Pacific Northwest as managers consider how much salvage logging to allow after fires in a spotted owl habitat. Aside from the consideration that permitting salvage logging could be viewed as a reward for arson, fires produce nesting holes for owls. Similarly, blowdown in riparian zones provides essential woody debris for stream channels.[23] Not only is disturbance necessary, but natural systems need to be allowed to reap the fruits of that disturbance. They also need to be allowed to recover.

Natural systems are often fairly slow to recover from disturbance. Recognition of that fact underscores the importance of considering the historical record of a site in order to understand its present condition. The present is contingent upon the past. This perspective is particularly important at this time, when so many systems that we consider natural are in fact rebounding from the onslaught of our ancestors.[24] The forests of the Southern Appalachians are an example of this phenomenon. The forests that once cloaked these hills were dom-

19. Resh, *supra* note 8.

20. NATIONAL RESEARCH COUNCIL, COLORADO RIVER ECOLOGY AND DAM MANAGEMENT (1991).

21. R.R. Johnson, *Historic Changes in Vegetation Along the Colorado River in the Grand Canyon in*, COLORADO RIVER ECOLOGY AND DAM MANAGEMENT 178-206 (1991).

22. BATTLE AGAINST EXTINCTION: NATIVE FISH MANAGEMENT IN THE AMERICAN WEST (W.L. Minckley & James E. Deacon, eds. 1991).

23. Stanley V. Gregory et al., *An Ecosystem Perspective of Riparian Zones*, 41 BIOSCIENCE 540 (1991).

24. For a clear elaboration of this point with respect to the American forest, see MICHAEL WILLIAMS, AMERICANS AND THEIR FORESTS: A HISTORICAL GEOGRAPHY (1989).

inated by huge individuals—trees so large that one logger tells a story of living in a dwelling hollowed out from a single tree. The forest was open and park-like: "My first descent and progress down the west side of the mountain was remarkably gradual, easy and pleasant, through grassy open forests for the distance of two or three miles."[25] Decades of logging, chestnut blight, and fire suppression have dramatically altered the Southern Appalachian landscape. The forests are no longer open and park-like, for rhododendron dominates the understory today, and not even a small child could live in a dwelling hollowed from one of today's logs.

Rivers and streams also bear the legacy of past human activities. The trapping of beaver in the 18th and 19th centuries largely eliminated from the landscape an animal that had been responsible for shaping river channels throughout North America for millennia.[26] In the absence of beaver, channels are less braided, food webs are altered, and retention of organic matter is greatly reduced. The rivers of the Southeast still bear the stamp of cotton farming—layers of silt meters thick, choking the channels and making the rivers run red with silt and clay after a rain storm. These rivers are a far cry from those described by William Bartram in the late 18th century. At that time, the rivers were so clear he could watch fish and crayfish while sitting on the river bank.[27] Our rivers also have been altered by wood removal from the channel.[28] Debris dams, formed from dead wood and accumulated organic matter, are an important feature of a stream channel, retaining organic matter and providing habitat for aquatic organisms.[29] Yet tens of thousands of debris dams were removed by early settlers so they could use the rivers for transportation.[30] The rivers have not yet recovered from that assault.

Rivers have also been impacted by logging practices of the last century. Splash dams[31] were built on streams; when enough water and

25. WILLIAM BARTRAM, TRAVELS THROUGH NORTH AND SOUTH CAROLINA, GEORGIA, EAST AND WEST FLORIDA 361 (1980).

26. *See* Robert J. Naiman et al., *Alteration of North American Streams by Beaver,* 38 BIOSCIENCE 752 (1988).

27. BARTRAM, *supra* note 25, at 143.

28. James R. Sedell & Judith L. Froggatt, *Importance of Streamside Forests to Large Rivers: The Isolation of the Willamette River, Oregon, U.S.A., From Its Floodplain by Snagging and Streamside Forest Removal,* 22 PROCEEDINGS OF THE INTERNATIONAL ASSOCIATION OF THEORETICAL AND APPLIED LIMNOLOGY 1828 (1982).

29. *See* Judy L. Meyer, *A Blackwater Perspective on Riverine Ecosystems,* 40 BIOSCIENCE 643 (1990).

30. Sedell & Froggatt, *supra* note 28, at 1830-32.

31. Splash dams were constructed of wood to create an impoundment behind them. Harvested wood was placed in the stream channel below the dam. When enough wood and water

cut logs were in the channel, the dams were blown up to float the logs downstream.[32] Needless to say, these debris torrents reamed out the channel. The Chatooga River, today a Wild and Scenic River, had splash dams on it in the 1800s. Clearly it would look different today without that legacy of logging.

Non-equilibrium concepts also apply to the maintenance of biodiversity, including the conservation of endangered species. If we follow the non-equilibrium paradigm, rather than simply trying to preserve a single species (the endpoint), we need to preserve the ecosystem of which it is a part and the process that has given rise to that interacting set of species, so that the assemblage can continue to change in response to environmental change. Our recovery plans need to ensure adequate population sizes and sufficient genetic diversity to maintain the ability of the species and the community to evolve and change in response to environmental variation. Species are not static objects; they must be able to change in order to persist.

Natural communities must also be able to change in order to persist. A landscape is composed of a mosaic of patches, each shifting in composition over time.[33] With a large enough landscape, we can expect to reach some stable distribution of patches in different stages of change. Some landscapes may however be too small relative to the size of patches that natural disturbances create, and a stable distribution will not be reached. This is clearly an issue faced by managers of national parks and other natural areas in our modern fragmented landscape.

The need to view landscapes as a shifting mosaic is particularly acute in dealing with wetlands regulation. A functioning wetland consists of interconnected habitats with different inundation frequencies; some patches may not be wet every year. Yet the mix of species present in the landscape requires that diversity of inundation frequencies. Wetlands are a patchy and dynamic landscape that require recognition of both local and regional variation for effective protection and mitigation.

had accumulated, the dam was exploded, and the resulting torrent of water swept the harvested logs downstream to the mill or a larger river. This practice had a devastating effect on the stream channel below the dam.

32. *See* James R. Sedell et al., *Fish Habitats and Streamside Management: Past and Present, in* PROCEEDINGS OF THE SOCIETY OF AMERICAN FORESTERS 244 (Society of American Foresters ed., 1982).

33. *See* F. HERBERT BORMANN & GENE E. LIKENS, PATTERN AND PROCESS IN A FORESTED ECOSYSTEM (1979).

The lack of stable endpoints in nature has implications for how we write regulations and assess the impacts of human activity. Consider the issue of preserving water quality. Over the past decade, we have achieved considerable water quality improvement by strict end-of-pipe regulations.[34] As we begin to tackle the problems of nonpoint pollution, it will be necessary to shift our regulatory emphasis to maintaining the ecological integrity of the rivers receiving the runoff. We cannot do this by establishing some threshold value of a metric or series of metrics that rivers have to achieve to be considered of high quality. Regardless of what we choose for this metric, it will vary with region, season, and year. Hence we need to establish regional reference systems that are free of inputs that threaten water quality. These reference streams could be used to provide information on the acceptable range of variation. Application of the Index of Biotic Integrity[35] is founded on this concept. In most parts of our nation, it is not possible to find pristine regional reference streams, and we are forced to compare with the least altered system. This approach of regulating within acceptable regional variation is an application of the non-equilibrium concept.

Danger lurks in misinterpretation of the new paradigm: if change is a part of nature, then can we view anthropogenic change as just part of the natural way? Absolutely not; the new paradigm is not a license for environmental abuse. Anthropogenic change differs from natural change in both quality and rate. It is more rapid and often of a type never before experienced by natural ecosystems (for example, exposure to man-made chemicals). Anthropogenic change is acceptable only if that change is within limits. The limits to change at a site are set by physiological capabilities of organisms present, evolutionary limits (only a certain number of species have evolved that are able to prosper under a given suite of environmental conditions), and historical limits (there is a group of species that has been able to reach the site).[36] In the past, evolution of new species and their migration has kept pace with changes that have occurred in Earth's history. Natural systems were able to adapt to past changes because they had a long time and large spaces; but anthropogenic change is rapid, and space is limited. We can use natural rates of change to help set acceptable

34. The phrase "end-of-pipe regulation" is used here to mean regulation of the concentrations or amounts of substances that can be discharged from a facility into receiving waters.

35. James R. Karr, *Biological Integrity: A Long-Neglected Aspect of Water Resource Management*, 1 ECOLOGICAL APPLICATIONS 66 (1991).

36. *See* Pickett, *supra* note 13.

limits for anthropogenic change. One important role for ecological science is to determine natural rates of change—to understand intrinsic variation in ecological phenomena over long periods of time.

II. Linkages are Extensive in the Landscape: Ecosystem Processes are Affected by Events in Other Ecosystems; Species Populations in Different Habitats are Connected such that Some Serve as Sources and Export Individuals to Others that Act as Sinks.

This concept, like the remaining concepts discussed in this Paper, is in many respects a corollary to the "disturbance" concept. It is an elaboration of the idea of the openness of natural systems. Our history of dealing with problems of eutrophication or acidification of lakes has taught us that activities in one part of the landscape greatly influence other parts. As we view aquatic ecosystems in a landscape context, it is critical to assess the strength of connections between ecosystems and to understand the linkages and processes controlling those connections. One effective way to do that is to focus on changes occurring at boundaries.[37] For example, reduced impact of agricultural nonpoint nutrient sources to a stream is possible when forested riparian zones are left intact.[38] Our laws need to recognize these natural connections in the landscape. As an example, we know that in many landscapes, streams and groundwater are linked physically, chemically and biologically.[39] Yet a legal scholar writes: "[t]he essential problem with groundwater law is fragmentation. In the past, lawmakers and courts have pretended that groundwater and surface water are not connected. They have failed to recognize that, while some groundwater is essentially isolated, most groundwater is really part of a stream."[40]

In some cases, a pipe that pumps water from a stream is subject to a different set of laws than a pipe that pumps water from the ground a few feet from the channel. This makes little ecological sense. What is needed is an approach that recognizes the connections between ecosystems—streams and groundwater—in the landscape.

37. *See* Paul G. Risser, *Ecotones*, 3 ECOLOGICAL APPLICATIONS 367 (1993).

38. *See* Richard R. Lowrance et al., *Riparian Forests as Nutrient Filters in Agricultural Watersheds*, 34 BIOSCIENCE 374 (1984).

39. *See* J.A. Stanford & J.V. Ward, *The Hyporheic Habitat of River Ecosystems*, 335 NATURE 64 (1988).

40. David H. Getches, *Controlling Groundwater Use and Quality: A Fragmented System*, 17 NAT. RESOURCES LAW. 623 (1984).

A similar recognition of connections is also essential when dealing with populations of species. The openness of systems and the dependence of one system upon events in another is dramatically illustrated by migrating animals, be they Pacific salmon, butterflies, sea turtles, neotropical migrant songbirds, or California grey whales that breed and give birth in Mexico and feed in Alaska.

Movements between habitats also occur for reasons other than long distance migration to breeding or feeding grounds. Ecologists recognize that individuals of the same species in different habitats can have very different reproductive rates.[41] In some habitats, referred to as sinks, the reproductive rate may be so low that the species is found in that habitat only because individuals have migrated there from another habitat (a source) where reproductive rates are higher. Finding individuals of a species in an area does not necessarily mean that the population is able to maintain itself in that area. This recognition has major consequences for species conservation. If we wished to preserve a species, yet preserved sink habitats while allowing development to proceed in source habitats, our preservation efforts would be in vain.

III. Indirect Effects can be as Significant as Direct Effects in Natural Systems.

This concept is another expression of the connectedness of ecological systems. Ecologists have long observed the importance of direct effects in ecosystems: for example, the response of lakes to nutrient additions from municipal wastewater. Yet it is not just these direct, "bottom-up" effects that influence aquatic ecosystems. "Top-down" and indirect effects are often equally important; altering higher trophic levels affects lower trophic levels in a "trophic cascade."[42] A simple description of a lake food web illustrates how this trophic cascade can be manipulated by lake managers. In a lake, algae are fed on by herbivorous zooplankton, which are fed on by planktivorous (plankton eating) fish like bluegill, which become food for piscivorous fish like bass. As bass numbers increase (for example, from stocking), bluegill numbers decrease, large herbivorous zooplankton like *Daphnia* increase and graze heavily on algae, which then decrease.

41. H. Ronald Pulliam, *Sources, Sinks, and Population Regulation*, 132 Am. Naturalist 652 (1988).

42. *See* Stephen R. Carpenter & James F. Kitchell, *Consumer Control of Lake Productivity*, 38 BioScience 764 (1988).

This trophic cascade can be used as a management tool; it is possible to reduce nuisance algae blooms by stocking a lake with piscivorous fish like walleye—an approach that is being tried in Lake Mendota in Madison.[43] It is important that regulators and managers recognize the multiplicity of control points in natural systems. Controlling nutrient inputs is important, but the structure of the food web will influence the effectiveness of that control measure.

IV. Populations Usually Show the First Sign of Environmental Stress.

I have included this as a relevant concept because I think it helps guide our decisions on how and what we monitor to detect human influence in the environment. The concept was convincingly illustrated in research on lake acidification.[44] In an experimentally acidified lake, many system level traits (like primary productivity) responded fairly slowly to the acidification, probably because of compensatory changes in a complex system. The most sensitive variables were at the population level: crayfish numbers, fish reproduction, or juvenile fish abundance.

V. Organisms not only Adapt to the Environment, They Modify it.

This is a conservative version of the Gaia hypothesis.[45] I include it here because I think we often forget how interdependent the physical and biological systems are on our planet. We readily accept a determining role for physical factors (for example, climatic influences on vegetation), but we forget the extent to which physical factors are influenced by biological activity. I offer two examples of this interdependence. One illustrates the physical consequences of the trophic cascade I discussed earlier. In small lakes, the presence of planktivorous fish alters the thermal structure of the water.[46] Where planktivorous fish are rare because they have been eaten by piscivorous fish, herbivorous zooplankton are abundant, algal biomass is low, water clarity is high, heat content is higher, and mixing depth is

43. Food Web Management: A Case Study of Lake Mendota (James F. Kitchell ed., 1992).

44. *See* D.W. Schindler et al., *Long Term Ecosystem Stress: The Effect of Years of Experimental Acidification on a Small Lake,* 228 Science 1395 (1985).

45. For an elaboration of the Gaia hypothesis, see J.E. Lovelock, Gaia: A New Look at Life on Earth (1979).

46. *See* A. Mazumder et al., *Effects of Fish and Plankton on Lake Temperature and Mixing Depth,* 247 Science 312 (1990).

greater. Temperature affects biology, but biology also affects temperature.

The impact of the biological world on the physical system is also apparent in terrestrial environments as illustrated by the second example, which is more global in scale. A global circulation model does a decent job of predicting global patterns of temperature and rainfall when rates of evapotranspiration are what one would expect from a vegetated planet.[47] But if the effects of plant evapotranspiration are removed from the model, it no longer provides reasonable predictions of global patterns of rainfall and temperature: it predicts no rain in Scotland and summer temperatures of forty-five degrees Celsius (one hundred and thirteen degrees Fahrenheit) in Chicago.[48] Clearly the biosphere has a marked influence on our climate.

This example of global temperature and precipitation patterns brings me to my final point, which is that ecology is global. Humans are altering a highly interconnected biosphere, and the actions of another state or nation can have major implications for our environment in the United States. Even if United States resource management were fully enlightened and environmental laws rigorously enforced, we would not be guaranteed a sustainable biosphere. It is critical that environmental law maintain a global perspective.

47. *See* J. Shukla & Y. Mintz, *Influence of Land-Surface Evapotranspiration on the Earth's Climate*, 215 SCIENCE 1498 (1982).
48. *Id.*