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CHAPTER 17

Disturbing Nature

IF THE OBSERVER always affects the observed, changing it from moment to moment, from glance to glance, then the observed also changes the observer. By the last decades of the twentieth century the biophysical environment had altered considerably from the days of Carolus Linnaeus and Gilbert White, and so had society, the economy, the scientific community, and its dominant ideas about nature. The world seemed more than ever in a tumult of change. By 1985 the human population was approaching five billion, doubling every forty years. All those people affected their surroundings, though to a varying degree. The landscape became a blur of motion. Nearly 500 million automobiles were on the roads, while planes of many nations streaked across the sky like a daily shower of meteors and communication satellites brought the news instantly from the embattled streets of Mogadishu or Los Angeles. What people saw from the vantage of those modes of transportation and communication was nature in upheaval. Each year about eleven million hectares of tropical forests and woodlands were destroyed; the effects could be tracked from space but apparently not prevented on earth. Meanwhile, more and more marriages were falling apart and institutions being discredited. Witness to all the extraordinary transformations going on, science changed its mind about a lot of things. Humans had become a profoundly disturbing element in the natural environment, and, in reaction, ecologists began to find the environment itself a disturbing thing.

On the first Earth Day, it seemed that the great coming struggle would be between what was left of pristine nature, delicately balanced in Eugene Odum's beautifully rational ecosystems, and a human race bent on mindless, greedy destruction. Two decades later, however, ecology had lost any clear notion of what pristine meant. Nature seemed less rational, less stable, and less harmonious. If there was any pattern out there, it was far more difficult to discern than earlier ecologists had supposed. The new views affected ecologists of every sort. Although Robert MacArthur had disagreed with the holistic-thinking Odum brothers about how science ought to be done, he shared with them, and with their common mentor, Evelyn Hutchinson, a belief that nature, at whatever level studied, tended toward equilibrium. The most natural state of nature was balance. That consensus fell apart. Another generation of ecologists began to question all the older ideas, theories, and metaphors, even to assert that nature is inherently unsettled.

Newspaper reporters did not commonly perceive that shift; as they covered oil spills, nuclear plant disasters, and carbon pollution, they continued to speak in terms of "upsetting the balance" and destroying "the ecology." Likewise, many scientists and land managers clung to the language of natural coherence and order. In a 1986 poll taken of its members by the British Ecological Society, 70 percent of the respondents ranked the "ecosystem" as one of the most important concepts their discipline had contributed to understanding the natural world; indeed, it ranked first on the list, outpolling nineteen other concepts. Other broad holistic ideas such as succession, energy flow, and conservation completed the top of the list. Most of the respondents were from the United Kingdom, and they were heavily biased toward "practical holism," including as they did large numbers of zoologists, conservationists, and geographers, and far fewer "theoretical reductionists" of the sort that had come to dominate many American research universities. The concept of predator–prey relations, consequently, was at the bottom of the list, along with population cycles.[1] But did the still popular idea of the ecosystem convey the same meaning it once did of a world of order and stability? Not at all, for many of the leading thinkers in ecology were already pulling away from Odum's influence, from the idea of the ecosystem as an integrated whole in a state of homeostasis, even from the word itself.

The newest Anglo-American textbooks in the field showed those trends unmistakably. Perhaps the most popular text in the United Kingdom was by Michael Begon, John Harper, and Colin Townsend, for whom the study of ecology was divided into three hierarchical levels: the individual organism, the population of a given species, and the ecological community, made up many populations. The ecosystem was conspicuously not one of those levels; out of six hundred pages, they devoted a single paragraph to the ecosystem concept, and then only to reject it as a nonentity. Similarly, the British authors R. J. Putnam and S. D. Wratten mentioned the ecosystem in passing but preferred to focus on competition among species as the conceptual heart of ecology. The same could be said for the big-selling American textbook author Paul Colinvaux and for newcomer Peter Stiling, whose introductory text of 1992 gave the ecosystem less than forty pages out of six hundred, with most of the emphasis going instead to such topics as natural selection, foraging for resources, food webs, and community change over time. More true to Odum's legacy was the Stanford team of Paul Ehrlich and Jonathan Roughgarden, who organized their text into the older four-tiered hierarchy, rising from the individual organism through populations and communities to the ecosystem (though Odum had reversed the order, starting from the top down as it were). And there was still Robert Ricklefs, turning out the several editions of his best-selling text, keeping the traditions alive by arguing for the essential orderliness of nature. Different authors, different emphases. Still, the field was perceptibly moving away from that unified theory that had sought to bring the living and the nonliving together into a single, coherent, balanced, and orderly system.[2]

A telling question that separated the generations was whether the outcome of ecological succession was a state of stability or not. When a new assortment of species en-

tered a landscape and replaced the one that was there, ecologists said succession had occurred. A pine grove replaced an aspen one, or oaks and hickories replaced a tallgrass prairie. If the sequence began on bare rock, the pattern of succession was called "primary"; when vegetation had been disturbed but the soil not destroyed, as when a fire swept across a prairie or a hurricane leveled a wood, ecologists spoke of "secondary" succession.[3] Either variety was supposed to reach a final resting point. Succession marched down a straight and narrow road to equilibrium, also called the climax or homeostatic stage. Burning down the climax forest, therefore, meant throwing succession into an earlier, more backward, and unstable state.

So had gone the conventional view. Then in 1973, the *Journal of the Arnold Arboretum* published an article by two scientists associated with the Massachusetts Audubon Society, William Drury and Ian Nisbet, challenging that view fundamentally. Their observations, drawn from southern New England's temperate forests, led them to assert that the process of ecological succession did not lead anywhere. Change went on in the composition of the landscape without any determinable direction, and it went on forever, never reaching any state of stability. They found no evidence of a progressive development over time: no trend toward biomass constancy, diversification of species, cohesiveness of plant and animal communities, or biotic control over the inorganic environment. Indeed, they found none of the criteria Eugene Odum had posited for mature ecosystems. The forest, they insisted, no matter what its age, was nothing but an erratic, shifting mosaic of trees and other plants. "Most of the phenomena of succession," they argued, "should be understood as resulting from the differential growth, differential survival, and perhaps differential dispersal of species adapted to grow at different points on stress gradients." In other words, they could see lots of individual species doing their own thing, but they could discover no emergent order among the species, nor any "strategy" to achieve one.[4]

Prominent among the authorities they cited in support of their view was the nearly forgotten Henry Gleason, who in 1926 had challenged Frederic Clements and his theory of the climax in an article provocatively entitled, "The Individualistic Concept of the Plant Association." Gleason had argued that we live in a world of constant flux and impermanence, not one tending toward stability. There was no such thing, he argued, as a balance of nature or an equilibrium or steady state. Each and every plant association was nothing but a temporary mingling of species along the road, here for a brief moment today and on their way to somewhere else tomorrow. The mingling was pure anarchy. "Each . . . species of plant," he wrote, "is a law unto itself," struggling against other species for resources. We look for cooperation in nature and we find only competition. We look for organized wholes, and we discover only loose atoms and fragments. We hope for order, but all we see is a wild jostling of species, each seeking its own advantage in utter disregard of the welfare of others.[5]

Gleason drew those conclusions from traveling along the Mississippi River, observing the alluvial forests, one of the most shifting environments in North America. Undoubtedly, he was right that such a flood-prone place never achieved any climax stage, and that discrete communities were hard to isolate and identify, but whether he was right to generalize that peculiar environment to the whole of nature was questionable. And that he chose to describe all of nature by the highly political term "individualistic" made him at least as guilty of metaphoric excess as any of the holistic ecologists. Despite those weaknesses, which had led earlier ecologists to dismiss his conclusions, Drury and Nisbet revived his lost reputation and theory. Eventually, their challenge to the climax theory became the core idea of what some scientists hailed as a new, revolutionary paradigm in ecology.

In 1977 two other biologists, Joseph Connell and Ralph Slatyer, continued the attack on climax or steady-state thinking by denying the old claim that an invading community of pioneering species, constituting the first stage in succession, worked to prepare the ground for its successors, like a group of Daniel Boones blazing the trail for civilization. The first comers, according to Connell and Slatyer, managed in most cases to stake out their claims and defend them successfully. They did not give way before a later

group of long-term settlers. Only when the pioneers died or were damaged by natural disturbances, thus freeing the resources they had monopolized, did latecomers find a foothold and get established.[6]

As this assault on established notions gathered momentum, the word "disturbance" began to appear more and more frequently in the scientific literature and be taken far more seriously. "Disturbance," connotating extreme exogeneous change, was not a common subject in Odum's heyday, let alone that of Clements or other founding figures, and it almost never appeared in combination with the adjective "natural." Now, however, it was as though scientists were out looking strenuously for signs of disturbance—especially signs of disturbance that were not caused by humans—and they were finding them everywhere, leaving little tranquility in primitive nature. Fire became a commonly mentioned disturber, so commonly in fact that nature seemed to be constantly ablaze. So was wind in the form of violent hurricanes and tornadoes, ripping through the trees and knocking them down. So were invading populations of microbes, pests, and predators. And then there were volcanic eruptions to be factored in. Grinding ice sheets. Devastating droughts. Above all, it was those last sorts of disturbances, caused by the restlessness of climate, on which the newest generation of ecologists fastened.

One of the most important expressions of the new post–Odum ecology was a book of essays edited by S. T. A. Pickett and P. S. White in 1985. Though some of the authors in the final section of the book dealt with ecosystems, the word had lost much of its original substance. Two authors in fact began by complaining that too many scientists assumed that "homogeneous ecosystems are a reality," when in truth "virtually all naturally occurring and man-disturbed ecosystems are mosaics of environmental conditions." "Historically," they wrote, "ecologists have been slow to recognize the importance of disturbances and the heterogeneity they generate." The reason for that reluctance was clear: "The majority of both theoretical and empirical work has been dominated by an equilibrium perspective." Repudiating that perspective, the authors took the reader off to the tropical forests of South and Central America and to the Everglades of Florida, demonstrating instability on every hand—a wet, green world undergoing continual disturbance, or, as they preferred to say, a world "of perturbations," big and small. Another essay described even the grasslands of North America as a regularly perturbed environment, a "dynamic, fine-textured mosaic" that was kept in a state of upheaval by the workings of badgers, pocket gophers, and mound-building ants, along with fire, drought, and eroding wind and water. The persistent message in the various essays was that the climax notion was dead, the ecosystem concept had receded into vagueness, and in their place stood the idea of the lowly "patch." Nature should be regarded as a shifting landscape of vegetative patches of all textures and colors, a veritable patchwork quilt of living things, changing continually through time and space, responding to an unceasing barrage of perturbations. The stitches in that quilt never held for long.[7]

This new picture was derived, as Gleason's had been, from observations made over rather short periods of time, and to be more fully credible the picture needed longer-term data. Those data lay buried in the sediments of lakes left behind by retreating ice sheets. Northern European scholars had been the first to go digging in such sediments. They had developed a technique known as palynology, the study of fossil pollen, which like old bones could be used to reveal nature's past. The leading American practitioner of the technique was Margaret Davis of the University of Minnesota, who undertook to rewrite the history of the North American forest from sedimentary archives. Standard plant distribution maps had long showed great sturdy kingdoms of deciduous forests lying across what is now the eastern United States, mixed forests surrounding the Great Lakes, boreal forests across the Canadian north, and to the far north the cold kingdom of tundra. But studied historically, those regimes proved to be as impermanent as any human ones. Davis took the Quaternary period, the last 2 million years during which ice sheets advanced and retreated in the northern latitudes, as her time frame. Had anyone taken time-lapse photographs of Minnesota or Massachusetts during that period, he would have had a dramatic story to show. During the last glacial maximum, 18,000 years ago, the ice

sheets covered a third of the continents, and the continental shelves lay exposed as the sea level fell. Even the tropics were affected by the glacial cycles, though far less violently. Vegetation everywhere had to shift out of the way of the ice or of colder, wetter air. Animals could fly or walk to more favorable climes, but the trees were much slower to migrate, and some species were much slower than others. Holistic ecologists had long assumed that species living together, needing each other, must have migrated en masse, and then, when the ice retreated, returned en masse. But Davis found no evidence for that communitarianism. They left in a ragged rout. Trees, to be sure, are by nature less dependent on each other than animals are; they seem to do little more than struggle for space against their competitors. In the great cooling they had shown themselves to be classic individualists.

As the climate began to alter again, warming rapidly and melting the last ice sheet, southern New England once again furnished a revealing window on that ragged scene. First, ponds and lakes dotted a tundra landscape, then spruce trees invaded for a while, then pines and birches came along about 8,000 to 9,500 years ago, making the area resemble modern-day Ontario. Then came the deciduous trees straggling back from their refuges in northern Florida and the lower Mississippi valley, each species following a different migration route and a different schedule. The hickories arrived some 4,000 years ago, the chestnuts 1,000 years later.[8]

Climate was the dominant reason for all that profound instability in organic nature. Clements had believed in long-term climatic regularities, allowing his grassland climaxes to persist, but according to Davis and other palynologists, he had been wrong. Davis, however, did not consider the time scale used by scientists like James Lovelock, which showed that the earth's climate, examined over eons not millennia, had been remarkably steady and the ice sheets were, from the perspective of outer space, only small blips on a large monotonous graph. Her sedimentary archives did not encourage that perspective; her time frame was shorter and the blips looked awfully big and irregular. "For the last 50 years or 500 or 1,000," she wrote, "as long as anyone would claim for 'ecological time'—there has never been an interval when temperature was in a steady state with symmetrical fluctuations about a mean.... Only on the longest time scale, 100,000 years, is there a tendency toward cyclical variation, and the cycles are asymmetrical, with a mean much different from today."[9] The evidence for that conclusion was ample; only its interpretation was open to dispute. Determining whether nature is "stable" or "unstable" depends entirely on where the observer stands, on what time scale is chosen, and on how the terms are used. Does stability mean a constancy of species in a given area, and is that constancy to be measured over months or decades or centuries or millennia or eons? Or does it mean a quality of resilience, a capacity for ecological communities to recover and reassemble after catastrophic disturbance, however frequently it occurs? Is the fact that there have been deciduous forests thriving someplace in North America over a span of tens of millions of years evidence of stability or instability?[10]

Standing in the same landscapes of North America but looking at other factors than climate, scientists could come to different conclusions than Davis drew. In the mid-1960s two forest ecosystem specialists, Herbert Bormann and Gene Likens, organized an experimental project in the Hubbard Brook section of New Hampshire's White Mountains National Forest, an area settled by white colonists two hundred years earlier and cut over repeatedly, now grown back to sugar maples, yellow birch, red spruce, and balsam fir. Inspired by Eugene Odum, they identified a half-dozen small "watershed-ecosystems" and began to study their species composition, nutrient cycling, biomass production, soil erosion, and the like. One unit they "devegetated" to observe the effects of bare slopes on stream runoff; other ecosystems they left intact. Over the next several decades the Hubbard Brook studies became the most famous in the United States for precision of data, number of publications, and comprehensiveness of approach. They also lent rather more support to Odum's theory of a steady state than to the Gleason–Davis picture of utter anarchy. Examined over hundreds, not thousands, of years, the forest showed little sign of catastrophic disturbance apart from the European axe. Fires set by lightning or Indians were uncommon, and

hurricanes seldom reached the area. Even when clear-cut by the colonists (removing almost every tree), the forests eventually recovered, showing in a few centuries the qualities of a mature ecosystem. Within that overall stability the experimenters admittedly found irregular patches where some of the trees were younger than the norm, leading them to describe the scene as a "shifting-mosaic steady state." The phrase nicely borrowed from the critics of Odum and Clements while reaffirming traditional thinking about the balance of nature.[11]

The protean text of nature was becoming a bible in the hands of many conflicting interpreters who could find a verse somewhere in its pages, often within the same chapter, for any creed or dogma they professed. Nonetheless, despite all the disputing over different texts, different places, and different scales, a gradual consensus began to emerge and it stressed the naturalness of disturbance. A major voice in forest ecology, Daniel Botkin, who had designed the computer program employed at Hubbard Brook, summed up the new opinion with an assured voice:

> Until the past few years, the predominant theories in ecology either presumed or had as a necessary consequence a very strict concept of a highly structured, ordered, and regulated, steady-state ecological system. Scientists know now that this view is wrong at local and regional levels... that is, at the levels of population and ecosystems. Change now appears to be intrinsic and natural at many scales of time and space in the biosphere.

"Wherever we seek to find constancy" in nature, Botkin wrote, "we discover change.... We see a landscape that is always in flux, changing over many scales of time and space, changing with individual births and deaths, local disruptions and recoveries, larger scale responses to climate from one glacial age to another, and to the slower alterations of soils, and yet larger variations between glacial ages."[12]

Now, of course, scientists had known about the Ice Age and droughts, individual births and deaths, raging fires and winds for a considerable time, though much of the sedimentary evidence was new. Yet until very recently they had not let any of those disruptions spoil their theories about balanced plant and animal associations. They saw and yet they dismissed such forces as relatively insignificant—not decisive threats to the prevailing order of nature. Why then did the post-Odum generation give so much weight to those same changes, often to the point of seeing nothing but instability in the landscape? Was it a matter only of recognizing new scientific evidence, or was it due to a deeper cultural shift going on?

Evidence supporting the former explanation came heavily from the growing subfield of population biology, that is, from ecologists who were not trained in ecosystem analysis. When they looked at a forest, the population ecologists saw only the various species of trees, and counted them—so many white pines, so many hemlocks, so many maples and birches. They insisted that if they could know all there was to know about the species that constituted a forest, and could measure their abundance in precise, quantitative terms, they would know all there was to know about that forest. It had no "emergent" or organismic properties, creating some whole greater than the sum of its parts, requiring holistic understanding. If ecosystems or communities existed, they did so as mere epiphenomena generated by the activities of individual species. Outfitted with computers that could track the rise and fall of those populations, and with a new array of theoretical models, logistic curves, and equations to describe the data, they brought a degree of mathematical precision to ecology that was awesome to contemplate.

On the other hand, more was going on in ecological theory than the rising influence of population studies. The longtime dean of populationists, Robert MacArthur, had used some of the same tools but come to very different conclusions than his successors. For him, as for later populationists, competition among species had been the foundation principle of ecology, as it was of life in general, and the structure of any ecological community was determined primarily by that competition. But MacArthur had believed that competition always produced a finely tuned balance in nature's machinery. Species swung back and forth as on a fixed pendulum, and the motion of their competitive interaction was exactly predictable. The newer populationists disagreed with that way of thinking. They insisted that any structure found in ecological communities was nothing but

the product of interactive populations, and then they insisted that they could find little if any balance. When they looked at population histories for any patch of land, they saw wildly swinging oscillations, not the rhythmic movements of a pendulum. Populations rose and fell erratically, like stock market prices, automobile sales, and dressmakers' hemlines. Nor did communities reliably exhibit the same structure under similar environmental conditions. We live, they began to insist, in a nonequilibrium world of many billion organisms bumping madly against one another.

One of the leaders of the new generation of populationists, John Wiens, explained how he had begun his studies "fervently embracing the existing views of competitively structured, equilibrium communities. But I have become skeptical of much of this dogma, and believe now that we know far less about the patterns and processes of communities than we think we do." Populations might even be so independent of one another that they might not compete at all. Their numbers might be determined not by the pressures of fighting over a limited amount of food, like rival bacteria in the constrained and controlled habitat of a Petri dish, but by completely unpredictable variations in the abiotic environment. According to another dissident, Robert Colwell, the landscape looked like "a sometimes turbulent and bewildering place where disturbance, natural enemies, biochemistry, life histories, and behavior play leading roles, along with the original cast of competitors." That was the way the world looked to the new populationists because, in large part, they looked at the old data with changed eyes.[13]

The most outspoken critic of the competition-leading-to-balance model in ecology was Daniel Simberloff, the defaunation expert of the Florida Keys. For him, the underlying issue raised by the revisionists was much larger than anyone had suspected; it was nothing less than whether ecology was to be placed on a true material basis or not. Science, he argued as had many others before him, depended on a material view of the universe. That meant purging it of all immaterialism, of "Platonic idealism and Aristotelian essentialism," which had viewed biophysical nature as the imperfect embodiment of fundamental, unchanging essences, like ideas in the mind of God, or like the ecosystem in the mind of Odum. Every super-organismic, holistic notion had to be weeded out of ecology, for there was no material substance to any of them. Precisely that, Simberloff said, was what Henry Gleason had tried to do back in the twenties—fight against the old metaphysics still lurking in ecology—and his plea for "individualism" had been a broom to sweep away the idealist cobwebs. But then Simberloff went on to assert that the biology of MacArthur had plenty of cobwebs of its own. Although indubitably materialist and reductionist, his work had been flawed by a faith in mechanistic determinism. Any rigid cause-and-effect theory, whatever its controlling metaphor, organicism or mechanism, was a lingering remnant of nonscientific thinking—shades of archaic idealism. MacArthur, like Odum or Clements, had tried to make nature into a single, coherent picture where all the pieces fitted firmly together. So for that matter had Sir Isaac Newton. So had anyone who talked confidently about specific causes always producing specific, exact effects. A genuine scientific materialism, in contrast, rejected determinism, because matter was fundamentally indeterminate and could not be wholly captured by any precise calculus. Nature was neither a simple machine nor a wispy ghost dwelling in the machine. The long war between the rival metaphors was over, both were exhausted and defeated. Nature, it was now claimed, followed the rules of chance, not necessity.[14]

What Simberloff came very close to saying was that all theories, all abstractions, all metaphors, in ecology were suspect, for all smacked of metaphysics. All of them tried to reduce the disorderliness of nature to a single all-encompassing idea, when it was "the individuality of populations and communities" that was "their most striking, intrinsic, and inspiring characteristic." The living world of nature was inherently a world of unique and unpredictable individual events, setting biology off from the physical sciences and making it difficult for physical scientists to understand biological phenomena. "We will not, in the future," he wrote, "have sufficient information or insight to produce equations as predictive as those of most physicists or engineers."[15]

The strenous effort that had gone into making the field of ecology over into a branch of physics, into emulating the big-money operations of the physical sciences, or into launching space-age projects like the International Biological Program had been misguided in Simberloff's view. In reacting hostilely to those efforts, he was clearly thinking about more than nature. When he admitted to being "inspired" by a nature that defied all firm predictions, he gave himself away. A world of chance implied a world of freedom, social as well as natural. The dominant traditions in ecology repelled him in large part because they reflected a kind of society, and a kind of science, he did not want to join: rigid, law-making, ordered, grandiose, bureaucratic.

Of course, Simberloff had his own comprehensive picture of the whole, his own set of abstractions, to push. He called his ecology a science of "probabilism." "The most complete statement which can be made about the world," he declared, "is a probabilistic one: a distribution of probabilities of states of the physical universe (or some part of it), or a specified statistical distribution of possible outcomes of some event." Probabilists believed in relative, not absolute, truth. Certainty in knowledge was unattainable, and thus all we could hope to establish was a likelihood that nature would act in this way or that. Probabilism spoke the language of the gambler: there was, it might say, a two-in-three chance that the next decade would become warmer than this one, there was a four-in-five chance that all the hemlocks in an area would disappear if it did. Organisms, it might be claimed, *generally* behaved in such and such a way, but in any given case the scientist could not be altogether sure they would. He could only offer an approximation.[16]

Simberloff admitted that there was something "profoundly disturbing" about a nature in which so much was unpredictable, so much had to be assigned to chance, so much freedom and randomness were at play. The idea of living in an unbalanced, unpredictable world raised people's fears, upset deeply seated views, threatened the secure. But that was the picture of nature many younger ecologists like himself began to embrace. Their hero in a struggle for acceptance was Charles Darwin, the great revolutionary of the previous century, the most important figure in the history of ecology, and a materialist through and through. Darwin had raised people's fears by unsettling their ideas about nature. He had had to fight against entrenched views with the authority of organized religion behind them. Nonetheless, he had succeeded in putting biology on a new, more modern basis. His theory of evolution through natural selection rejected the idea of species as fixed entities, or ideal types, created by God in the beginning of time, but also rejected the archaic image of organic nature as a precisely balanced machine resembling the planets moving in their spheres. Evolution, he showed, was a more ragged and opportunistic process than traditional thinking or common metaphors had allowed. No one could predict what new creatures might evolve next. The world was open-ended.

Such a reading of Darwin as the father of ecological probabilism was not completely plausible. He had indeed overthrown the notion of species as ideal types arrayed in a divine plan and insisted on explaining things in pure, material terms, with no recourse to mysterious indwelling forces or an anima mundi or a directing spiritual power. But for all that, Darwin was not really a probabilist. He did not, that is, think of nature as fundamentally stochastic, changing in random ways that did not observe strict, simple laws of cause and effect. Indeed, his views more closely anticipated those of Robert MacArthur a century later in that he understood competition to be the dominant process in nature and was sure that competition always produced a tightly interwoven structure of balance and order.

Darwin, however, had become almost everybody's hero in ecology, an authority that many rival ecologists wanted on their side. His name had earlier been recruited by the critics of Odum's ecosystems ecology. That paradigm had come to seem, in its rather static functionalism, to be very un-Darwinian, and a shift had begun toward an "evolutionary ecology," as G. H. Orians first proclamed in 1962. Instead of merely describing the interrelationships of living organisms with their environment, or explaining how things functioned, ecology must show how they had come to be what they were—the why of relationships as well as the how. By that point in the history of science the whole

study of evolution was enjoying a powerful renaissance, a "new synthesis" it was called, in which Darwin's natural selection and Gregor Mendel's genetics were joined together into a single program of research. Biologists now believed they had the full set of theories needed to understand the lives of organisms. They could give a reason, better than any that Darwin could give, as to why variations among plants and animals appeared in the first place—namely, the recombination of genes through sexual reproduction; and they also had refined Darwin's explanation for why some variations survived and others did not—the selective pressures of the environment. Although the latter theme was through-and-through ecological, the ecologists had been slow to take part in the new synthesis, allowing the geneticists to dominate. They were too interested in functional analysis of ecosystems. Now, that lag was much regretted. As John Harper declared, "The theory of evolution by natural selection is an ecological theory—founded on ecological observation by perhaps the greatest of all ecologists. It has been adopted by and brought up by the science of genetics, and ecologists, being modest people, are apt to forget their distinguished parenthood." But not for long, as suddenly Darwin came looming out of the shadows, his face before every ecologist. The title of Evelyn Hutchinson's book of essays, *The Ecological Theater and the Evolutionary Play*, published in 1965, captured the newly awakened interest in Darwinism perfectly: ecologists must take as their proper province the study of the theater in which the drama of evolution was unfolding.

The rediscovery of Darwin was also a rediscovery of competitive struggle as the leading theme in biology, and it forced ecologists to look for competition where many had been firmly convinced nature showed mainly a spirit of altruism and cooperation. Science must get back to the bloody warfare of tooth and claw. Then came a question of profoundly disturbing implications: If competition was indeed so important in making the ecological theater what it was, then on what level of biological organization should they be looking? Which entities were actually doing the competing, which were the real actors in the play? Was it ecosystems that were competing against one another? Was it communities? Or was it really only the individual organisms? If the ecosystem was supposed to be the key entity in ecology, then what was the ecosystem competing against—other ecosystems? How, unless there were two or more ecosystems fighting to possess a plot of land, could the ecosystem be a real entity after all, shaped by the forces of evolution? How, for that matter, could an entity as big as Gaia, the total system of life on the planet, be considered real, a product of natural selection? Gaia, argued some critics, had no competitors on this earth, and logically could have none. If there was no competition, if there could be none at the level of the whole planet, there could be no selection going on. And if there was no selection, then there was no evolution, no existence, no entity. Earlier ecologists had tried to escape that rigorously reductive Darwinian logic by suggesting that supra-individual entities had emerged through "adaptation" to their environment, not through competition; that is, they had evolved through trying to fit themselves to their surroundings without taking it away from rivals. But in 1966 the staunchly neo-Darwinian biologist George Williams exploded such thinking by showing that even adapting to the environment could be achieved only by individual organisms, not groups. There was no such thing, he argued, as "group selection." If he was right, and most ecologists believed he was, then that was a devastating blow against all holistic ecosystems thinking.

The turn toward Darwinistic evolutionism characterizes the past two or three decades in ecology, though "turn" hardly conveys the turbulent heterogeneity of the science in that period, the heated controversies over cooperation versus competition, wholes versus parts, populations versus ecosystems that have touched scientists' beliefs in the deepest way. Neo-Darwinism was itself premised on the primacy of conflict. Its proponents dismissed cooperation-centered ecology as bad science that had tried to find in nature some support for their ethical point of view—their "love thy neighbor" views, as George Williams snorted. But then, as we have seen, the battles did not end there with a resounding triumph over benign holism, for those who had carried the Darwinian banner of competition were soon overtaken

from the rear by a boisterous group claiming to be themselves the true heirs of Darwin. They wanted to paint on the banner the words "random" and "stochastic," even if doing so meant painting over the words "competition," "balance," and "stability." The logic of Darwinism for them led finally to the conclusion that the world was always in the making, always impossible to predict. If the individual organism was indeed the key player, and there was less and less disputing that view, then we could not say exactly what the individual would do. Freedom would rule.

Behind the neo-neo-Darwinism of Simberloff, Wiens, and others was more than a wrangle going on within the ranks of ecology over who should carry the banner of Darwin. Similar ideas about stochaticism and instability were appearing throughout the mathematical, natural, and social sciences, as well as within the humanities, indicating a change occurring within the worldview of all advanced technological societies. It was nothing less than the discovery, and even in some circles the celebration, of disorder. All nature, all human life, many began to claim, is *fundamentally* erratic, discontinuous, and unpredictable. The world is full of surprising events, and they keep hitting us in the face. Dark clouds collect overhead, with rain appearing imminent, and then abruptly they disperse and the rain doesn't fall, leaving the weather forecasters looking sheepish. Cars suddenly bunch up on the freeway, and the traffic controllers fly into a frenzy, all their plans gone awry. A man's heart beats regularly year after year, then suddenly begins to skip a beat now and then, and the physicians are uncertain why. A Ping-Pong ball bounces off the table in an unexpected direction. Each and every little snowflake falling out of the sky turns out to be completely unlike any other, due to minute differences in their conditions. All those were ways in which nature seemed to be imponderable and inconsistent. If the ultimate test of any body of scientific knowledge was its ability to predict events, then the sciences, despite so many grand successes, were frequently failing the test.

Making sense of that failure was the mission of an altogether new kind of inquiry calling itself the science of chaos. Some said it portended a revolution in thinking that was equivalent to quantum mechanics or relativity. Like those other theories, the theory of chaos rejected tenets going back as far as the days of the founders of modern science. In fact, what was occurring was not two or three separate theories popping up in different disciplines but a single revolution rising up against all the principles, laws, models, and applications of classical science, the science ushered in by the great Scientific Revolution of the seventeenth and eighteenth centuries.[17]

Throughout the modern era the scientific community had assumed that nature, despite a few appearances to the contrary, was a perfectly manageable system of simple, linear, rational order. The metaphor for that system had been the clock, arguably the dominant machine of the modern age. Nature ticked on and on with clocklike precision. Sir Isaac Newton had believed that image and had tried to write the mathematical equations that would describe all the gears and wheels whirling inside the apparatus. The French mathematician Pierre Simon de Laplace had agreed: Give him all the facts, he promised, and he would describe that clockwork order in complete detail. Standing outside and above nature, he would plot all the lines along which everything must move, the speed of movement, and the collisions that must occur. He would, that is, become like God, who already had all the facts. For some scientists and philosophers in the twentieth century, the invention of the computer seemed to bring that godlike knowledge closer to human grasp, but then the computers started to reveal a surprising degree of disorder, unperceived by pencil-and-paper calculators. Even the simplest equations could generate on the screen a motion that was so complex it appeared random. For whatever reason, whether because the empirical data suggested it or because extrascientific cultural trends did—the experience of so much rapid, unpredictable, disturbing change in the world around them—scientists were beginning to pay attention to what they had long managed to avoid seeing. Nature was far more complex than they had ever realized, or indeed, some were beginning to hint, than science ever could realize.[18]

Chaos was, like Gaia, a word that came welling up from

the lost pagan cosmology of ancient Greece to seize the imagination of avant-garde scientists. If the earth goddess had long ago brought life and order into existence, then chaos had been her opposite: the realm where disorder still ruled, a dark underworld that had existed before creation did and where the dead were still condemned to dwell. Chaos was evil, Gaia was good. Without ever quite acknowledging its parentage, modern science had been in a sense the offspring of Gaia, growing up with a strong, unquestioned faith in the benevolent rule of law and order in the universe. Acting on that faith, scientists had seen themselves as discoverers of the "laws of nature." Now, however, they began to wonder whether they had been wrong. Perhaps nature was ruled by that primordial lawless force after all, and order was only the dream of man. Instead of order happily emerging out of chaos, it was chaos that kept boiling up from the darkness, breaking down order.

The scientific study of chaos began (if one could talk thus about so pervasive a set of ideas) in 1961 with efforts to simulate weather and climate patterns on a computer at the Massachusetts Institute of Technology. There, meteorologist Edward Lorenz came up with his now famous "butterfly effect," the notion that a butterfly stirring the air today in a Chinese park can transform the storm systems appearing next month over a North American city. Scientists called that phenomenon a "sensitive dependence on initial conditions." What it meant was that tiny differences in input might quickly become substantial differences in output. A corollary was that we could not know, even with all our artificial-intelligence apparatus, every one of the tiny differences that were occurring at any place or any point in time; and even if we could, we still could not know which tiny differences would produce which particular substantial differences in output. Which butterfly in which park and which particular flap of its wings should we pay attention to? Which storm, which flood, going on thousands of miles away? There were simply too many variables to plot all the lines of influence, of cause and effect. As a consequence, scientists must acknowledge that nature is essentially nonlinear in its processes. Weather was the classic example of that fact: Weather was emphatically nonlinear. Beyond a short range of, say, two or three days, weather predictions were not worth the paper they were written on.

The implications of the "butterfly effect" for the field of ecology were profound. If a single flap of an insect's wings on another continent could lead to a torrential downpour in New York City, then what might it do to the Greater Yellowstone Ecosystem? What could ecologists possibly know about all the forces impinging on, or about to impinge on, any piece of land, any community of organisms? What could they safely ignore in the way of exogenous forces and what must they give strict attention to? What distant, invisible, minuscule events might even now be happening that would change the very structure of the plant and animal life in our backyards? That was the challenge presented by the science of chaos, and it altered the imagination of many scientists dramatically.

Despite the growing popularity of the new ideas, however, ecologists were among the last to become interested in them and only a few ever made a full conversion to the science of chaos. But a discernible move toward the new way of thinking came in 1974 when Robert May, a physicist from Australia who moved to the biology department at Princeton and eventually took over Robert MacArthur's chair in the department, published an essay on ecology with the word "chaos" in its title.[19] He admitted that the mathematical models he and others had been trying to construct for various populations were inadequate approximations of the ragged life histories of organisms. They did not fully explain, for example, the aperiodic outbreaks of gypsy moths in eastern hardwood forests or the Canadian lynx cycles in the subarctic. Wildlife populations often did not follow some simple pattern of increase, saturation, competition, struggle, and balance. One could find, to be sure, many stable points and cycles, but one could also find everywhere the hand of chaos.

In the previous year May had published a book that overturned one of the oldest and most widely accepted arguments in ecology, that the more diversified the species are living in an area, the more complex their linkages are, and the stabler the system is. Charles Elton had been among

the earliest to support that idea with scientific evidence showing that northern tundra landscapes, which had very few species, were far less stable than tropical ones, where much of the planet's biological diversity dwelled. Conservationists had found that idea intuitively right, and they had called for preserving species diversity as the key to preserving a stable environment. In contrast, May, working with theoretical models on a computer, found that the more species there were, the more fragile was the system. "Confronted with disturbances beyond their normal experience," he noted, such communities tended to crumple. Above all, the tropical rainforests seemed the epitome of permanence, but in fact they were so fragile that some had begun to term them "nonrenewable resources," for once cut down, they did not regenerate. In contrast, much simpler communities were often able to spring back, following a disturbance, and restore themselves. In the United States, for example, the east coast marsh grass, *Spartina alterniflora*, grew in vast homogenous stands that resembled agriculture's monocultures, and therefore ought to have been vulnerable to instability; but actually it proved to be remarkably stable through all the vicissitudes of weather. May cautioned that he was not advocating the turning of diverse nature into industrialized corn or wheat fields, for the latter did not have the "evolutionary pedigree" of nature's monocultures.

> Until such time as we better understand the principles which govern natural associations of plants and animals, we would do well to preserve large chunks of pristine ecosystems. They are unique laboratories. Quite apart from valid ethical and aesthetic considerations, there are pragmatic reasons why we should query the increasingly universal replacement of natural ecosystems, with their long evolutionary history, by agroecosystems, which are usually intrinsically unstable.

Although at that time May was still using the ecosystem concept, his subsequent research into chaotic behavior focused increasingly on stability and instability within the populations of discrete species.

In his 1985 Croonian lecture for the Royal Society of London, May took up a problem straight out of Gilbert White's ramblings around Selborne. White had made an annual count of the number of swifts in the village and consistently found eight pairs. Two centuries later there were still six pairs regularly found in residence, a remarkable example of nature's constancy. On the other hand, White had found no wasps on his fruit trees in 1781, then two years later he found "myriads" of them, an example of nature's irregularities that had continued right down to the present. The point was that species did not all exhibit the same demographic patterns. Some remained numerically constant over long periods of time, others oscillated greatly from generation to generation but always around a stable long-term norm, while still others fluctuated radically each year, with no apparent norm, even when weather conditions were steady, suggesting there was something chaotic in their genetic makeup or response to environment. All those species differences had an impact on the structure of nature. May remained confident that every individual species pattern was "deterministic," that is, had identifiable causes, and that even the nonlinear irregularities would one day be found to have discernible boundaries so that science could build mathematical models of them. Yet the variability found among species made the science of ecology far more complicated than had long been supposed.[20]

Subsequently, May, who moved on from America to Britain, became the most widely cited figures in the standard college textbooks of ecology. His followers in research tried to track down and capture those nonlinearities in species abundance, whether among Canadian predators or human viruses, trying to bring their subject into line with chaotic theory. Among them was William Schaffer, who though originally a student of MacArthur's, was struck like May by the anomaly of unpredictable population fluctuations. Though taught to believe in "the so-called 'Balance of Nature,' " he wrote, "the idea that populations are at or close to equilibrium," ecological patterns began to look very different than that. He described himself as having to reach boldly across the disciplines in order to make connections with the theory of chaos developing in the other natural sciences in order to free himself from his field's restrictive past. Ecologists, he began admitting to himself, could never specify a system's state at any given time with infinite precision; therefore, they could never make long-term predictions about what would happen to its various species, whether in response to external perturbations or to the species' own behavioral dynamics. But with others they could make a science out of those conditions.[21]

Thus, the new ecology of chaos was not a total surrender to the idea of disorder, or to a philosophy of complete indeterminism, or to some obscurantist repudiation of science itself. Rather, ecologists were saying that if there was any order out there, it was going to be much more difficult to locate and describe than they had thought, and that it would always have an unruly element of indeterminancy in it. Perhaps some of them were beginning to sense that, as observers, they were always themselves standing in the picture they were observing, influencing it by their presence. Science can never get on the outside of nature, like the Judeo-Christian God, disinterested, remote, and detached, but must be carried on from within the whole—never seeing that whole completely but only its parts impinging on the observer, reacting to the observer. Yet the pursuit of science would not be abandoned because of this difficulty. May and others would not give up altogether their dream of finding rational order; it was too entrenched a faith, too vital to the mission of their lives, to toss aside abruptly. So, chastened but not discouraged, they looked for the limits or boundaries of chaos, the regularities of irregularity. As Ian Stewart explained, the mathematics on which chaos theory depended began to treat order and chaos as two distinct manifestations of an underlying determinism.[22] Nature could exist in a variety of states, some ordered, some chaotic, all connected in a continuous spectrum. If harmony and discord could be combined into beautiful music, then order and chaos might be combined into beautiful math and beautiful ecology.

Modern science lurches on from theory to theory, fad to fad, intellectual breakthrough to breakthrough, with breathless new claimants to a Nobel Prize appearing each and every season. The latest fashionable set of ideas, following chaos, was complexity. It promised still another grand, comprehensive, interdisciplinary theory about the nature of matter and energy, time and space, one linking physics, biology, and even history, anthropology, and economics into a single inquiry; and once more there were a number of ecologists joining in the search for the underlying commonalities. Complexity, according to one interpretation, was "the emerging science at the edge of order and chaos." If nature showed a fundamental capacity to be disorderly, it was pointed out, then order also had to be acknowledged and studied. There might not be any large overarching order inherent in nature, but there was plenty of evidence of conditions of change giving way to those of order, of order dissolving into change. The elements might stay the same but continually they rearranged themselves into new patterns, like a kaleidoscope turning round and round from one glittering starburst to another. We must conceive of ecosystems then, not as permanent entities engraved on the face of the earth but as shifting patterns in the endless flux, always new, always different. Ecosystems emerged out of the evolutionary turmoil in the grasslands or coral seas just as human kingdoms, empires, and civilizations arose out of the constant turmoil in people's lives, and then they fell apart. Like eddies appearing in a turbulent stream, such complex systems did not last forever, but while they lasted they showed an astonishing capacity for dynamic cohesion, stability, and order. Why was that? What organizing principles did all such complex systems have in common? What explained the sudden appearance of that order, structure, and organization from time to time, and how and why did that order often persist in the face of so much disorderliness all around?

With the arrival of complexity theory the questions agitating theoretical science had come full circle. First, the idea of a fundamental tendency toward equilibrium in nature had been challenged and thrown out by scientists, disequilibrium appearing to be a truer state of being. Then equilibrium began to reappear as a widespread potentiality within nature that required explaining. The most recent theories brought science back to ancient insights, long neglected, particularly the view that unresolvable contradictions exist in nature and yet somehow they merge into one unified flow. As the economist Brian Arthur put it, the discovery of complexity recovered the wisdom in such old philosophies as Taoism, which holds that "the world started with one, and the one became two, and the two became many, and the many led to myriad things."[23]

The utilitarian and moral implications in those cascading waves of thinking in the scientific community were at least as difficult to sort out as the ideas themselves. Did chaos theory, for example, promote, in Ilya Prigogine and Isabelle Stenger's words, "a renewal of nature," a less hierarchical view of life, and a set of "new relations between man and nature and between man and man"?[24] Or did it increase modern man's alienation from nature, his withdrawal into doubt and self-absorption, driven by fear that nature was becoming impossible to understand? What was there to admire or respect in a nature characterized by so much stochastic irregularity? How were people supposed to behave if that characterization of nature were true? If there was so much natural disturbance going on anyway, why should humans be worried about introducing a little more of it—adding a bit of rearranging of their own? Why not go ahead and flap their wings in the park, along with the butterflies, free of guilt that they might be doing any special damage? What, after all, did the phrase "environmental damage" mean when there was so much natural upheaval and unpredictability all around? Did the postwar environmental movement to which Paul Sears, Eugene Odum, and Rachel Carson belonged, or the conservation tradition that preceded them, make sense any longer or offer direction?

Ecologists seemed divided among themselves on the advice they gave to society on how to act on the earth. One group, reflecting some of the new disequilibrium thinking, began to challenge the public perception that ecology and environmentalism were one and the same thing. Some ecologists were bored with trying to preserve the planet in a state of health. Thomas Söderqvist, in a study of ecology in Sweden, which followed fashions similar to those in Britain and the United States, concluded that members of the most recent generation in the field

> seem to do ecology for fun only, indifferent to practical problems, including the salvation of the nation. They are mathematically and theoretically sophisticated, sitting indoors calculating on computers, rather than traveling out in the wilds. They are individualists, abhorring the idea of large-scale ecosystem projects.

Indeed, the transition from ecosystem ecology to evolutionary ecology seems to reflect the generational transition from the politically conscious generation of the 1960s to the "yuppie" generation of the 1980s.[25]

That characterization should not be applied to every scientist who published on patch dynamics or disturbed regimes or chaotic predator–prey cycles, but it did draw attention to an unmistakable tendency among many of the post-Odum generation to disassociate themselves from environmental reform as much as from his unified ecosystem theory. For some scientists, a nature characterized by highly individualistic associations, constant disturbance, and incessant change was clearly more ideologically satisfying than Odum's ecosystems, with their connotations of cooperation, collective action, and environmentalism.

An American case in point was Paul Colinvaux, author of the popular introduction to neo-Darwinian ecology, *Why Big Fierce Animals Are Rare* (1978). His chapter on ecological succession began with these highly political lines: "If the planners really get hold of us so that they can stamp out all individual liberty and do what they like with our land, they might decide that whole counties full of inferior farms should be put back into forest." Clearly, he was not enthusiastic about land-use planning or forest restoration, or indeed about environmentalism as a whole. Colinvaux was very clear about the need to get some distance between himself and groups like the Sierra Club. Then he ended that same chapter with revealing and self-assured words:

> We can now . . . explain all the intriguing, predictable events of plant successions in simple, matter of fact, Darwinian ways. Everything that happens in successions comes about because all the different species go about earning their livings as best they may, each in its own individual manner. What look like community properties are in fact the summed results of all these bits of private enterprise.[26]

Apparently, if this writer was any indication, the old *social* Darwinism was back on the scene, walking the halls of science, and at least some of the turn away from Odum's generation might have owed something to a revulsion among scientists toward what they perceived as a threat to capitalistic and libertarian values.

Others, however, drew somewhat different conclusions from the recent disequilibrium trends in ecology. Daniel Botkin was one of the most articulate advocates of a new, chastened set of environmentalist policies. Arguing for a "new ecology for the twenty-first century," he recommended an environmentalism that was more friendly toward manipulating and dominating nature. The world of nature he compared to a symphony hall where several compositions were being played at once, "each with its own pace and rhythm." Humans, he advocated, should put themselves in the position of nature's conductor. "We are forced to choose among these [compositions], which we have barely begun to hear and understand." If there was any order to be heard in nature, it must be our achievement. "Nature in the 21st century," he argued, "will be a nature that we make." Enlightened by the recent trends in ecological theory, humans had arrived at a new view of earth "in which we are a part of a living and changing system whose changes we can accept, use, and control, to make the Earth a comfortable home, for each of us individually and for all of us collectively in our civilizations."

Botkin, like Colinvaux, criticized the early phases of the environmental movement for its radical, sometimes hostile, rejection of modern technology and progress. We need a science of ecology, he believed, that approaches economic development in a more "constructive and positive manner." The environmentalism of the postwar years had been "essentially a disapproving, and in this sense, negative movement, exposing the bad aspects of our civilization for our environment." Now, science showed that such gloomy negativism was unwarranted and should be replaced by a stance "that combine[s] technology with our concern about our environment in a constructive and positive manner."[27]

Those recommendations constituted a new permissiveness in ecology—a new tolerance toward accommodating human desires for greater wealth and power than early environmentalism had allowed, a more tolerant science than the ecology of Sears, Commoner, Carson, or Odum, with its emphasis on the preservation of a balanced nature, had been. The disturbance-impressed ecology of Botkin and others accepted human demands as the primary test of what should be done with the earth, and their list of acceptable demands was expansive. They denied that there was any firm guide to behavior to be found in nature, past or present, or even much reason for limiting human wants or rejecting progress. But their "ecology for a new century" was often very vague on what kind of conservation specifically should be practiced. The only guidance Botkin offered on which human disturbances were okay and which were not was an observation that slow rates of change were "more natural" than rapid ones and therefore more desirable. "We must be wary," he warned, "when we engineer nature at an unnatural rate and in novel ways."[28] But what did that formula really mean? What was unnaturally rapid or novel under so restless a sky?

Earlier, the equilibrium theorists had confidently claimed that they could determine what was safe for humans to do and what was not. Their standard advice had been to take from nature only a sustainable yield from healthy ecosystems, without harming the resilience or stability of the whole. Scientists thought they could determine with relative ease what that yield should be. They had only to determine the steady-state population levels in the ecosystem and then calculate how many fish could be caught each year or how many trees could be harvested or how much pollution could be absorbed without affecting the wonderful balance. Humans must learn how to take off the interest in nature's economy without touching the fixed capital. Now, however, the very concept of what was a normal yield or output had become far more ambiguous. Botkin showed that it was just such misguided assurances of stability in natural populations that had led to overfishing the California sardine industry—and to the total collapse of that industry in the 1950s.[29]

If the natural populations of fish and other organisms were in such chaotic flux that scientists could not confidently set maximum sustained yield targets, could they instead discover a more flexible standard of "optimum yield," one that would allow a more generous margin for error and fluctuations? That was where most expert advice came to rest in response to the new trends in thinking: Harvest freely all the commodities you need from nature, but do so at a slower rate to avoid overstressing a system in stochastic change. But then the experts still had to discover what that safe optimum rate was, and it could not be discovered without addressing the more basic challenges raised by recent ecological thinking about what was optimal in a natural world subject to so much disturbance, so much unpredictable turbulence.

Precisely at that point applied ecology found itself getting incoherent as it turned away from a unified systems theory or theory of competitive balance. It was in danger of losing any sense, intuitive or empirical, of what a healthy environment looks like. Had that been the final upshot of the disequilibrium and chaotic paradigm in ecology, then popular environmentalism must eventually find itself wandering confused and uncertain, without its scientific tutor. But then by the late 1980s and early 1990s scientists of the post-Odum and post-MacArthur generation began to find their way toward a revived environmentalism. A new cause emerged for many of them—the conservation of biological diversity, or "biodiversity." Ecologists began to argue that, whatever the uncertainties of theory, we must prevent the extinction of any and all species of plants or animals at the hand of man, and that the accumulated knowlege of biotic populations, so erratically rising and falling, could help us do just that. Even if we could not determine rigidly what a healthy ecosystem was, or a healthy state of homeostasis for the earth, or even identify a clear point of stable balance between competing species, we could at least use the new insights of ecology to save declining species, populations, communities, and ecosystems from extinction. Ecology, which had become the immensely complicated study of the fluctuating abundance of species, must now become an instrument to stop an alarming trend toward plant and animal losses.

Despite centuries of scientific exploration, no one really knew just how many species were out there in the world. Three million seemed a sure minimum, but the maximum number might be as many 30, or even 100, million. The canopies of the tropical rain forests alone might be the home of tens of millions of insect species, living out their lives high above the ground far from human eyes. Each year 1 percent of the planet's rain forests was cleared for agricultural purposes, mainly cattle grazing. Consequently, many irreplaceable species must be disappearing each year without any scientist ever discovering them. The recent rate of extinction was perhaps the greatest experienced by that particular biome over the last 150 million years, mounting to as high as 10,000 species a year in the last decade of the twentieth century. The public joined in the growing scientific concern about extinction, though generally it worried more about losing the charismatic species like mountain gorillas, Indian tigers, or Oregon's spotted owls than the less appealing phyla, where the loss was actually greatest. Almost anywhere one looked in the plant and animal kingdoms, the picture was getting very grim: an acceleration of extinction so great that it amounted to a reversal of the processes of biological evolution. Millions of years, even hundreds of millions of years, of natural selection were suddenly being undone by the explosively increasing numbers of Homo sapiens.

One man who found the uncharismatic insects an especially appealing, lovable lot was the Harvard ecologist Edward Wilson, who, as we have seen, had been a friend and colleague of Robert MacArthur's. Wilson became one of the most active leaders in the cause of conserving biodiversity on earth. He had worked in the South American tropics repeatedly, as well as the Florida mangrove islets, and had a passionate feeling for their beauty and liveliness. Now, under the threat of losing that treasure, he began to preach the need for a new conservation ethic, one inspired by the land ethic of Aldo Leopold but focused on preserving individual species more than community integrity. "Every species allowed to go extinct," he wrote,

> is a slide down the rachet, an irreversible loss for all. It is time to invent moral reasoning of a new and more powerful kind, to look to the very roots of motivation and understand why, in what circumstances and on which occasions, we cherish and protect life. The elements from which a deep conservation ethic might be constructed include the impulses and biased forms of learning loosely classified as biophilia.

Biophilia was supposed to be an innate human tendency to love other living things and care about their survival; it was

a plausible but highly speculative notion. That such a tendency might evolve culturally into a new preservationist ethic toward other forms of life was decidedly hopeful thinking. Nonetheless, to rally scientists as well as the public behind that ethic became Wilson's great personal mission. In 1986 he organized and chaired a National Forum on BioDiversity in Washington, and in that same year the Society for Conservation Biology was founded.[30]

The growing sense of urgency for preserving species diversity caught up many population biologists, along with ecosystem ecologists, and indeed scientists of every sort. One of the most prominent leaders, Michael Soulé, explained that many of the scientists were trying to get out of the small academic box they had made for themselves and rejoin a broader intellectual and moral community. Conservation biology offered a broader engagement, an escape from intellectual isolation and elitism. Self-interest also motivated many, for their research sites were being spoiled in many places by rapid development.[31] Whatever their motivation, scientists tried to forge a new consensus among themselves: Whatever disagreements they may have had about progress, technology, the balance of nature, the predominance of cooperation or competition in nature, or of chaos or order, preserving biological diversity became a unifying imperative. All the other social and environmental threats, including pollution and resource depletion, paled beside this one and demanded a strong scientific response. "This is the folly," Wilson warned, "our descendents are least likely to forgive us."[32]

By the last decade of the century the science of ecology, after so many intense, complicated theoretical debates, found itself in a more uncertain state of mind about its implications for modern technological civilization than it had been in the two or three decades following World War Two. Yet, surprisingly, it also found itself regrouping around a new conservation ideal that was, if not exactly required by new theories, at least was not contradicted by them. Apparently, moral ideals have a way of unexpectedly precipitating themselves out of the flux of events, the uncertainities of theory. As one set of environmental perceptions and values faded away, another began to take its place. Nature, ecologists began to argue, is wild and unpredictable. Nature is in deep, important ways quite disorderly. Nature is a seething, teeming spectacle of diversity. Nature, for all its strange and disturbing ways, its continuing capacity to elude our understanding, still needs our love, our respect, and our help.

The Disorder of History

Science, I have been suggesting in these pages, is not a single-minded, monolithic force marching through time. It is not the pure, disinterested search for knowledge many of its supporters make it out to be, nor is it an undeviating advance along an "edge of objectivity," as others have claimed, nor is it what some critics have called a purely "alienated vision." None of those notions adequately reflects the ever-changing reality of the scientific enterprise. Science has had as many schisms, conflicts, dissensions, and personality contrasts as any human activity. A less protean enterprise could never have accommodated so many minds or described so many of nature's patterns. Precisely because of that internal diversity of outlook, science has contributed vastly to expanding our vision of the natural world and of our place within it. Science has been a house with many doors, some leading to one view of nature, some to another. But as the philosopher William James wrote of his summer cottage in New Hampshire, those doors have generally opened outward.[33]

Ecology has been one of the more interesting dimensions of this eclectic scientific inquiry. Over more than two centuries of growth, it has given us a wide array of perspectives on nature, all of which can claim some degree of truth. Many of ecology's past ideas linger in the air today. One can still hear now and then the ideas of Carolus Linnaeus or Gilbert White, of early imperialists or arcadians, of the finely contrived balance-of-nature idea. Then at other times one can hear the echoes of Romantic biology, of holistic organicism, and of Thoreau's subversive encounter with nature. There is no escaping the persistence of the past. Ecology in the late twentieth century is inevitably the product of its long and complex intellectual tradition regardless of how

strongly it believes in its own novelty or validity. Failing to accept that indebtedness to the past, or to realize how diverse and contradictory that past has been, we will not make much headway toward a deep understanding of our current ideas about nature.

Despite many floating echoes from the past, however, a strong trend in ecology has been apparent over time: its picture of nature has been thoroughly historicized, beginning in the nineteenth century, but especially accelerating during the past two decades, until ecology has become a branch of history. I do not mean by history a mere department or discipline in the university, or history as a record merely of human achievement. Rather, I mean history as a more general sense of the past, nature's past as well as humankind's past, and a sense of how that past was different from the present. I mean, in other words, history as a concern with change over time, with development and evolution and becoming. How that historicization altered science is the theme of a book by Stephen Toulmin and June Goodfield, entitled *The Discovery of Time.* "The picture of the natural world we all take for granted today," they point out, "has one remarkable feature, which cannot be ignored in any study of the ancestry of science: it is a *historical* picture."[34] The new picture began to emerge during the period 1810 to 1830 as scientists began to realize how much time had transpired on the earth and how much had changed over that span of time. A static world of fixed, hierarchical relations began to give way to another nature, evolving, contingent, revolutionary, conflicted, catastrophic at times, always in a state of flux. Geology was the first science to discover time; the first great geologists, James Hutton, William Playfair, and Charles Lyell, were all historians of deep time, finding the annals of former worlds written in beds of chalk and old red sandstone.

It is no coincidence that the modern academic discipline of history had its roots in that same era when scientists began to discover deep time. Like the newly discovered fossils lying embedded in the dust, waiting to be exhumed and analyzed, great political empires of the past had to be dug up and explained. A generation that had been through many profoundly interrelated revolutions could not help wondering how long it would be before the next upheaval came along. Thomas Jefferson, one of the most ardent students of ancient empires, called for making a revolution in every generation. The future promised to be unlike anything ever seen before, and the past became its mirror, full of strange, exotic ruins demanding explanation. Historians like Gibbon, Macauley, Michelet, von Ranke, Bancroft, and Parkman began to write long, eloquent meditations on the meaning of the past.

Nor is it a mere coincidence that the same century that created the modern study of history, that became fascinated by a very long human chronology, that discovered in the fossil record the traces of countless extinct species, saw the appearance of the theory of evolution through natural selection. Charles Darwin turned biology into history—the history of flora and fauna jostling for space, branching out to new territory, overthrowing established regimes. According to Toulmin and Goodfield, Darwin's book *On the Origin of Species* "broke down the artificial barrier between Science—which had hitherto been concerned with the static Order of Nature—and History, which studied the development of humanity. So the two most powerful intellectual currents in the nineteenth century were united. Whether we consider geology, zoology, political philosophy or the study of ancient civilizations, the nineteenth century was in every case the Century of History—a period marked by the growth of a new, dynamic world-picture."[35]

But with Darwin, as with other thinkers of the nineteenth century, change was never all there was. Change led somewhere; it had a positive direction, conventionally called Progress. Darwin described evolution as a blooming tree of life, suggesting that change was coherent and contained, like the growth of an organism, whose parts increase or even replace one another but the whole remaining one entity. Once taken root, that tree of life goes on growing forever, until it covers the earth. Nature, like human society, told a story of constant upheaval, but the observer could still find a benevolent order and pattern in the story.

Out of that new historicized biology came the field of ecology, though it was not until the 1890s that ecology could be said to have achieved a disciplinary status. How could the new science be anything but historical, born as it was at the end of the great century of historical and developmental consciousness? Its founders, including Ernest Haeckel, Eugenius Warming, and, early in the twentieth century, Henry Cowles and Frederic Clements, were all intensely aware of the biological and geological past, of time's arrow flying unstoppably over the land. Like Darwin, however, they believed that change is not at all disorderly or directionless. Change unmakes order but also makes it anew. Despite a thousand mishaps, nature has its regularities, its great coherences that persist over time, giving the landscape a standard of normality.

Toulmin and Goodfield to the contrary notwithstanding, the growing fascination with the past remained, until very recently, compartmentalized into two distinct and separate spheres, one for people and another for the rest of the natural world. The former sphere, the human story, was the first to lose a sense of order and break down into narrative chaos. Following such traumas as the Holocaust and the atomic bomb, or more benign upheavals such as the sexual revolution and global trade, human history became tumultuous, unpredictable, and at times profoundly destructive. Meanwhile, the second sphere of historical consciousness, the history of nature, still seemed to the scientific as well as the popular mind to be an orderly, predictable, and conservative sphere. The great challenge facing humankind, proclaimed the popular ecological literature of the 1960s, was to rescue human history from its self-destructive energies and bring it into conformity with the stabler history of nature.

I grew up with that sort of thinking, as did so many other historians and ecologists, and still find plenty of good evidence and solid reason to support it. The history we are writing on the planet has become more destructive than ever, destructive of species, of biological communities, of ecosystems, and of our own security and happiness; clearly we need a different way of living than the one we have been pursuing. But can nature unequivocally and unambiguously furnish that way? Does nature provide us with a set of overarching norms for redirecting the history of humankind?

If I had written a history of the United States in the 1960s, the era of Odum's prominence, that described the nation as moving through a series of predictable "developmental stages" to a condition of maturity characterized by lower net production but higher stability (i.e., resistance to external perturbations), higher diversity, closed mineral cycles, good nutrient conservation, and low entropy, my colleagues would have wondered what substance I was abusing. Unlike nature, the nations of the world, it was commonly understood, may "develop," but they never reach a steady state. In that decade the United States was certainly a highly developed country, at least in industrial terms, but its population was growing, not stabilizing, its resources were depleting, its cities were burning, its streets were filled with antiwar protesters, many of its leaders were getting shot. An observer of those changes might well have asked why the history of American society should be so much more chaotic than the history of an oak-hickory forest. Why should the past thousand years of human activity look so much more unsettled than the past hundred million years of other species?

But now, as we have seen, scientists have abandoned that equilibrium view of nature and invented a new one that looks remarkably like the human sphere in which we live. We can no longer maintain that either nature or society is a stable entity. All history has become a record of disturbance and that disturbance comes from both cultural *and* natural agents, including droughts, earthquakes, pests, viruses, corporate takeovers, loss of markets, new technologies, increasing crime, new federal laws, and even the invasion of America by French literary theory.

One of the most important insights of the modern discovery of time is that all ideas, past, present, and future, are grounded in particular historical contexts. That discovery includes the ideas of politicians, businessmen, scientists, and even historians—it covers *all* ideas. We call this insight the principle of historicism, or historical relativism. Supposedly, it gives us greater objectivity toward and sympathy for the people of the past who could not share our blessings of enlightenment; at the same time, it is supposed to free us from any blind allegiance to present-day opinions. If we must explain the past in its own terms, as historicism argues, then we must also be wary of uncritically accepting the conditions that govern our own way of thinking.

The intent of these chapters has been to include the science of ecology within the purview of historicism, to argue that ecological ideas are only valid relatively, that they are suited to and rooted in their times.[36] Science must not be exempted, as it often is, from this kind of analysis; nor can the scientist, by any act of will or training, isolate his or her perception of nature from the rest of mental life. In all intellectual endeavors there may be certain timeless tests of logic and empirical validation to be met, but there are also biases of selectivity and emphasis derived from the environing culture and from deeply felt personal experience. This history of ecological ideas has shown how impossible it has been to screen out such biases. Any attempt to do so, to divorce nature from the rest of the human condition, leads to a doctrine of intellectual and moral alienation, in which scientific consciousness tries to deal coolly, abstractly, with a nature distanced from the needs and concerns of humanity. In truth, science has no more claim to absolute truth, permanence, infallibility, or comprehensiveness than any other field of thought. As Arthur Lovejoy once noted, the history of all ideas leads to an understanding of how "every age tends to exaggerate the scope and finality of its own discoveries, or re-discoveries, to be so dazzled by them that it fails to discern clearly their limitations and forgets aspects of truth of prior exaggerations against which it has revolted."[37] Undoubtedly, this tendency to denigrate the past and exalt the present is a useful trait when one needs to believe in the truthfulness of one's own ideas, and scientists have been perhaps no more guilty than any others in this regard.

Carried far enough, the philosophy of historicism teaches us that we must also try to write the history of our obsession with history. We must try to understand, that is, the fixation on radical change that has characterized our recent outlook. Where is it coming from? The obvious answer is that it is coming from the experience of rapid social transformation that has been gaining momentum. Earlier generations, going back hundreds of thousands of years, experienced change too, but in a very different context. According to Claude Lévi-Strauss, "the characteristic feature of the savage mind is its timelessness; its object is to grasp the world as both a synchronic and a diachronic totality."[38] Later, in post–hunting and gathering societies where agriculture dominated daily life, the idea of change still remained more cyclical than linear; the recurrent cycle of annual crops was more immediately real to people than the long-term evolution of human life. Nature appeared as a permanent order, created in the beginning of time by decree or coming spontaneously into being but never altering in its essential properties or relations. That, however, is not the way modern people understand the world or time, and the reason must lie in our changed material and cultural circumstances.

We live on the other side of a revolution in consciousness brought about by the forces of modern capital, technology, and economic materialism. The description of those forces is too complicated to go into here, but despite a bit of hyperbole and oversimplification, Karl Marx and Friedrich Engels were largely right when they credited modern capitalism with creating a new passion for change and a new attitude toward time.

> Constant revolutionizing of production, uninterrupted disturbance of all social conditions, everlasting uncertainty and agitation distinguish [this] epoch from all earlier ones. All fixed, fast-frozen relations, with their train of ancient and venerable prejudices and opinions, are swept away. All new-formed ones become antiquated before they can ossify. All that is solid melts into air, all that is holy is profaned.[39]

Marx and Engels were thinking primarily about the effects of capitalism on ideas of social community in the transition from an ancient rural to a modern urban setting, but we can see how readily their words also apply to our understanding of the natural order. The sense of the ecological whole that once seemed so solid and unshakable has tended, along with all other ideas, to melt into air.

Marx and Engels welcomed that new sense of flux, indeed built their theory of dialectical materialism on it, following the great philosopher of history, Georg Wilhelm Friedrich Hegel. Marx and Engels believed that the undermining of traditional ideas about time and order was necessary to free

people from the prejudices of the past. You cannot, therefore, find in them much concern about preserving any ancient feeling for nature or even any concern for environmental preservation. But they did predict that one day history would come to an end in a timeless utopia of the classless society. The disorder of constant economic upheaval would cease and society would finally reach a steady state of established relations, an equilibrium of justice, when nature too would exist in some state of equilibrium, though one firmly under technological control. That prediction seems to have been proved wrong in recent decades. After World War Two the pace of change has, in fact, not slowed down but on the contrary has accelerated remarkably. Moreover, we have seen not the achievement of justice for all but rather an exacerbation of global inequalities. Today, for many, the socialist dream of a glorious end to capitalist turmoil has collapsed and lies in shambles.[40]

Industrial capitalism, blaring its triumph over all rivals, promising a "new world order" in which there is to be an endless pursuit of wealth, offers no promise whatever of ever achieving a steady state in either social, economic, or ecological terms. Its ruling vision is one of ceaseless change, infinite possibilities, and boundless creativity. In light of its past record we can expect that global capitalism will continue to promote unchecked economic and population growth, will continue to stoke the rising aspirations of the poor without really satisfying them, and will intensify its currently intense demands on nature. The effect of that economic culture will be to dissolve whatever fragmentary notions of stability, order, or normality are left to us, and we will be left more than ever dwelling in a world where change has become the dominant principle of life.

So, in this manner, we historians can explain the modern tendency to turn nature into a mirror image of our society, reflecting back the chaotic energies of capital and technology. And by offering that kind of explanation we can free ourselves from a mindless, uncritical allegiance to the new orthodoxy, as historical analysis has liberated us from previous orthodoxies and promoted critical thinking. Fortified by the principle of historicism, we can approach recent ecological models that dramatize disturbance with a sense of skepticism and independence. If they are not the mere reflection of global capitalism and its ideology, they are nonetheless highly compatible with that force rearranging the earth. The newest ecology, with its emphasis on competition and disturbance, is congruent with what Frederic Jameson has called the "logic of late capitalism."[41]

But having glimpsed that connection between the science of ecology and its cultural and economic conditions, are we then free to believe something else? The answer must be yes, and yet also no. The philosophy of historical relativism grants us freedom from dogmatic thinking but no firm guidance to belief. It cannot really invalidate the intellectual tendencies of our time, or any other time, or offer new ideas of order to believe in. On the contrary, historicism can eventually lead either to a complete cynicism or to the acceptance of any set of ideas or any environment that humans have created as thoroughly legitimate. By the logic of historicism Disneyland must be as legitimate an environment as Yellowstone National Park, a wheat field as legitimate as a prairie, a megalopolis of thirty million people as legitimate as a village. Each has been the product of history and therefore each must stand equal to any other. Each offers unique dynamics to be probed and understood, but any set of historical dynamics, like any set of beliefs or institutions, must appear to the consistent historicist to be as good as any other.

If the study of human or natural history required us to adopt such a rigid historicist position, then I would be ready to join those who call for the wholesale rejection of modern historical consciousness as a corrupting worldview. I would accept the arguments of that trenchant critic of modernism, Edward Goldsmith, who has called for a rejection of recent ecology and a harkening back to a prehistorical and premodern consciousness, to a chthonic or folk worldview that antedates modern historical thinking.[42] But such a wholesale rejection is neither possible at this point in time nor is it required of us; accepting modernity or its historical worldview does not oblige us to embrace all of modernity uncritically or to adopt an extreme version of historicism. We can acknowledge the flow of history, going back at least

two million years for humans, billions for the rest of nature, without getting completely lost in the labyrinths of time. I want to suggest now several conclusions that it seems to me our knowledge of the ecological past, both humankind's and nature's, allows us to draw. They are conclusions that transcend our present-day circumstances. They seem to me to be as objectively true as we can make them, supported by substantial evidence and reason. And they are conclusions that cover *both* nature and human society, acknowledging that we cannot set up any impermeable barrier between the two spheres.

In the first place, informed reason allows us to say that living nature, for all its private, individualistic strivings, works by the principle of interdependency. Indeed, it can only work by that principle. No organism or species of organism has any chance of surviving without the aid of others. John Muir once declared, "When we try to pick out anything by itself, we find it hitched to everything else in the universe."[43] New proof of that interdependency principle has come to light in the postwar era. Send any individual organism or any population of organisms into outer space alone, without any of the services provided by other kinds of organisms, from soil fertility to oxygen generation, and it will not survive. It needs its evolutionary companions.

For a while to be sure, many human beings lost sight of that truth, even began to imagine that they could live by their technological prowess alone. But the past few decades have demolished that illusion. All the changes we find going on in civilization, it is now clear, are only changes in the patterns of that interdependency, not in the reality or extent of the interdependency itself. What we call the environmental movement of the post–World War Two era has been essentially a reawakening to the realization that we must depend on other forms of life to survive; we have no other options. Progress has not made our condition different in this respect from that of our remotest ancestors. Being clever and adaptable, we have learned how to make substitutions in our dependencies and to alter the geography of our dependency—for example, North American Indians have learned to buy and eat Central American beef instead of Canadian moose—but we have not learned how to live on a planet that is dead.

The full implications of our ecological dependency are still working their way into the heads of economic and political leaders, but already they are eroding any grandiose claims of conquest over the earth and of our invulnerability before the forces of nature. Consequently, the extinction of obscure species has become a global concern, expressed in international treaties. Communities, states, and nations are no longer so sure they can manage without those species, even if many of them play only a remote, distant, or obscure role in human welfare. At the same time an awareness of our dependency on the whole fabric of life is stimulating a sense of dependence on other people, most of them strangers to us but locked with us in a common predicament. Again, the forms of dependency may change. The solidarity of the face-to-face group, working together for survival, may become transformed into something larger, perhaps something less effective, into a single global audience instantly tuned into the fate of victims of disease, tyranny, poverty, or forest destruction wherever they live. Thus, the fact of interdependence binding all living things into a kind of community has not been invalidated by the rapid pace of recent change or the many uncertainties that change has produced.

In the second place, our study of the past has uncovered models of successful adaptation that we can learn from today. They are not values in themselves but rather are lessons drawn from nature, applicable to the values we have chosen. The natural world may not provide any overall, sufficient norm for us to follow, or any single transcendent good that we can discover, but it does provide a wealth of models, depending on what it is we want to achieve. If we want to fly, for example, we can find models in the wings of birds, models that took tens of millions of year to perfect. If we want to stop soil erosion or survive drought, we have a model in the tallgrass prairie, which retains far more of the rain that falls than a wheat monoculture does and can bound back from a severe dry spell that would completely kill a planted domestic crop. We may not think about such models as lessons derived from history, but they are all the

products of past experience, and it is the biologist, thinking historically, who reveals how they came into being, by a process of evolution that we can call the unfolding wisdom of life.

Similarly, environmental history sets before us models of human communities that have been more successful in using resources than we in some respects. For example, if social longevity is high in our hierarchy of values, if we want to survive as a people and as a species for the longest possible time, then we can find in the past a wealth of examples that have something useful to teach. We cannot find in the past or present any societies that are perfect in every aspect, or examples that we can simply revive lock, stock, and barrel from extinction; but we can find models to study and learn from. They exist within the borders of the United States and in every part of the earth—communities that have managed to fit themselves to their places for impressively long periods of time, that are less destructive of the biota around them, that may have acquired some vital knowledge of place that we lack. They may have not escaped the hand of time, but they have come closer than we to withstanding it. My own research as a historian suggests that such enduring communities, whether based on hunting-and-gathering techniques or on agriculture, have had one dominant characteristic: they have created rules, and many of them, sometimes highly intentional rules and at other times rules embedded in folk tradition, but always rules based on intimate local experience, to govern their behavior. They have not tried to "live free" of nature or of the group, nor have they resented restraints on individual initiative, or left it to each individual to decide completely how to behave. On the contrary, they have accepted many kinds of limits on themselves and enforced them on one another. Their methods of enforcement may not meet our modern American standards of privacy or of justice, or be compatible with our modern sense of strong personal rights, and certainly they can stifle creativity or originality. But throughout history, having those rules and enforcing them vigorously seems to be a requirement for long-term ecological survival.

How we use such models from other eras and places to inform the values or norms chosen for our own lives is a very difficult question. Clearly, we cannot merely turn all our wheat fields, no matter how inadequate ecologically they may be, back into bluestem prairies, nor can we turn industrial capitalism back into a medieval alpine village or an Australian aborigine's camp. We simply cannot go back in time and undo all that has happened. We are, in that sense, prisoners of time. But we can approach the record of the past with much more respect, admitting that most of the innovations we have recently made are not likely to survive, that what is old among us may by that very fact be worthy of respect and mimicry, that what is *very* old may be wise.

In the third place, history reveals not merely that change is real but also that change is various. All change is not the same, nor are all changes equal. Some changes are cyclical, some are not. Some changes are linear, others are not. Some changes take an afternoon to accomplish, some a millennium. We can no more take any particular kind of change as absolutely normative than we can take any particular state of equilibrium as normative. The fact that ice sheets once scraped their way across Illinois does not provide any kind of justification for a corporation that wants to strip coal from the state. We know this, but sometimes we get confused by talk about all change being "natural." In a loose sense, the statement is true, but it is also meaningless. No one really maintains that whatever is is right, or that whatever happens is good. We understand that there are changes in nature that work against us as well as for us, changes that we have to defend ourselves against, even if we cannot prevent them. The challenge is to determine which changes are in our enlightened self-interest and are consistent with our most rigorous ethical reasoning, always remembering our inescapable dependency on other forms of life.

Environmental conservation becomes, in the light of this historical awareness, an effort to protect certain rates of change going within the biological world from incompatible changes going on within our economy and technology. It is not a program of locking nature up within a museum case, freezing it for all time. Rather, it is a pattern of behavior based on the idea that preserving a diversity of change ought

to stand high in our system of values, that promoting the coexistence of many beings and many kinds of change is a rational thing to do. The pace of innovation in computer chips may be appropriate to a competitive business community, but it is not appropriate to or always compatible with the evolution of a redwood forest. Some things take longer to grow or improve. Some things cannot adapt as fast as others. These are differences revealed by the history of nature and society. Today, historians of every sort can no longer can claim that there is a single universal narrative of change that all species, all communities, all places must conform to. "History" has given way to "histories." Each of those histories needs space in which to play itself out, to unwind its narrative. That is precisely what the modern idea of conservation must aim to do: provide the space, either set aside in large discrete blocks or protected within the interstices of the landscape, so that all the many earthly histories can coexist—the history of a coral reef alongside the history of a coastal city, the history of a tropical rain forest alongside the history of a political struggle. Such a strategy of trying to conserve a diversity of changes may seem paradoxical, but it is founded on a crucial and reasonable insight. We may have to live with change, may even be the products of change, but we do not always know—indeed, we *cannot* always know—which changes are vital and which are deadly.

These are conclusions about the real world, I believe, that the intertwined study of nature and society leads us to make today, conclusions that stand up well because they are based on knowledge and reason, not merely on private fantasies. Whether we choose to learn from the past or not, the past is our most reliable instructor in reality. We no longer can locate nature in some timeless state of perfection, accessible through perfectly detached science, nor do we have revelation or authority to depend upon. Only by understanding that constantly changing past, a past in which humankind and nature were always one integrated whole, can we discover with the aid of imperfect human reason, all that we value and all that we defend.

39. Eugene P. Odum, *Ecology and Our Endangered Life-Support System,* prologue.

40. Peter J. Taylor, "Technocratic Optimism, H. T. Odum, and the Partial Transformation of Ecological Metaphor after World War II."

41. Howard T. Odum, *Environment, Power, and Society,* pp. 274–84.

42. W. Frank Blair, *Big Biology,* p. 163. For British participation, see E. Barton Worthington, *The Ecological Century,* pp. 160–77. See also Robert P. McIntosh, *The Background of Ecology,* pp. 213–21.

43. A thorough account of MacArthur's work and his influences is Sharon E. Kingsland, *Modeling Nature.* Kingsland sees MacArthur as rejecting the historical thinking common in traditional biology since Darwin, with its emphasis on the evolution of the unique individual or event. "The very act of imposing mathematics (or any model) on nature often involved a rejection of history in favor of a harmonious, unifying concept" (p. 8).

44. MacArthur wrote that "the ecologist and the physical scientist tend to be machinery oriented, whereas the paleontologist and most biogeographers tend to be history oriented" (*Geographical Ecology,* p. 1).

45. MacArthur and Wilson, *The Theory of Island Biogeography,* p. 181.

46. Edward O. Wilson and Daniel S. Simberloff, "Experimental Zoogeography of Islands."

47. Stephen D. Fretwell, "The Impact of Robert MacArthur on Ecology," pp. 9–10.

48. Yrjö Haila, "On the Semiotic Dimension of Ecological Theory," pp. 378, 382–83. See also David Abram, "The Mechanical and the Organic: On the Impact of Metaphor in Science," in *Scientists on Gaia,* ed. Stephen H. Schneider and Penelope J. Boston, pp. 66–74.

49. Lawrence J. Henderson, *The Fitness of the Environment: An Inquiry into the Biological Significance of the Properties of Matter* (New York, 1913).

50. Lynn Margulis and James Lovelock, "Gaia and Geognosy," in *Global Ecology,* ed. Mitchell B. Rambler, Lynn Margulis, and Rene Fester, p. 6; Odum, *Ecology and Our Endangered Life-Support Systems,* pp. 59–64. The conference on Lovelock's ideas was held in 1988 in San Diego, California, and published as *Scientists on Gaia.* The most hostile paper was given by James W. Kirchner, of the Department of Geology and Geophysics at the University of California at Berkeley, who argued that the hypothesis offered, in its weaker form, nothing new, and in its stronger form, was untestable; he objected mainly to the implication that Gaia was a purposeful entity (pp. 38–46).

51. James Lovelock, *The Ages of Gaia,* pp. 94–96. Lovelock referred to the appearance of free oxygen in the air as the first and greatest pollution catastrophe in earth's history, for it devastated the anaerobic bacteria.

52. *Ibid.,* pp. 203–23.

53. *Ibid.,* pp. 174–75; James Lovelock, *Gaia,* pp. 107–22.

54. James Lovelock, *Healing Gaia,* p. 18.

Chapter 17

1. J. M. Cherrett, "Key Concepts: The Results of a Survey of Our Members' Opinion," in Cherrett, *Ecological Concepts,* pp. 1–16.

2. See Michael Begon, John L. Harper, and Colin R. Townsend, *Ecology,* pp. 591–92. R. J. Putnam and S. D. Wratten, *Principles of Ecology,* p. 43. Peter Stiling, *Introductory Ecology,* pp. 358–96. Robert E. Ricklefs, *Ecology,* esp. chap. 2. See also Robert Leo Smith, *Elements of Ecology,* 2nd ed. (New York, 1986), which admits that the author has shifted from an "ecosystem approach" to more of an "evolutionary approach" (p. xiii).

3. A clear discussion of both types of succession can be found in Paul Ehrlich's *The Machinery of Nature,* pp. 268–71.

4. William H. Drury and Ian C. T. Nisbet, "Succession," *Journal of the Arnold Arboretum* 54 (July 1973): 360.

5. Henry A. Gleason, "The Individualistic Concept of the Plant Association."

6. Joseph H. Connell and Ralph O. Slatyer, "Mechanisms of Succession in Natural Communities and Their Role in Community Stability and Organization," p. 1140.

7. Orie L. Loucks, Mary L. Plumb-Mentjes, and Deborah Rogers, "Gap Processes and Large-Scale Disturbances in Sand Prairies," pp. 72–85, and James R. Karr and Kathryn E. Freemark, "Disturbance and Vertebrates: An Integrative Perspective," in S. T. A. Pickett and P. S. White, *Ecology of Natural Disturbance,* pp. 154–55.

8. Margaret B. Davis, "Palynology and Environmental History During the Quaternary Period."

9. Margaret Bryan Davis, "Climatic Instability, Time Lags, and Community Disequilibrium," p. 269.

10. This argument is made by Mark Williamson, "Are Communities Ever Stable?" in *Colonization, Succession and Stability,* ed. A. J. Gray, M. J. Crawley, and P. J. Edwards (Oxford, 1987), pp. 353–70.

11. F. Herbert Bormann and Gene E. Likens, "Catastrophic Disturbance and the Steady State in Northern Hardwood Forests."

12. Daniel Botkin, *Discordant Harmonies*, pp. 10, 62.

13. John A. Wiens, "On Understanding a Non-Equilibrium World: Myth and Reality in Community Patterns and Processes," in Donald R. Strong, Jr., Daniel Simberloff, Lawrence G. Abele, and Ann B. Thistle, *Ecological Communities*, p. 440. Cowell quoted in Roger Lewin, "Predators and Hurricanes Change Ecology," p. 738.

14. Daniel Simberloff, "A Succession of Paradigms in Ecology," pp. 13–22.

15. *Ibid.*, pp. 25–26.

16. *Ibid.*, p. 11.

17. This argument is made by Ilya Prigogine and Isabelle Stengers in their book *Order Out of Chaos*. Prigogine won the Nobel Prize in 1977 for his work on the thermodynamics of nonequilibrium systems.

18. An excellent account of the change in thinking is James Gleick, *Chaos: The Making of a New Science*. What Gleick does not explore are the striking intellectual parallels between chaotic theory in science and postmodern discourse in literature and philosophy. Postmodernism is a sensibility that has abandoned the historic search for unity and order in nature, taking an ironic view of existence and debunking all established faiths. According to Todd Gitlin, "Post-Modernism reflects the fact that a new moral structure has not yet been built and our culture has not yet found a language for articulating the new understandings we are trying, haltingly, to live with. It objects to all principles, all commitments, all crusades—in the name of an unconscientious evasion." On the other hand, and put more positively, the new sensibility leads to a new emphasis on democratic coexistence: "a new 'moral ecology'—that in the preservation of the other is a condition for the preservation of the self." See Gitlin, "Post-Modernism: The Stenography of Surfaces," *New Perspectives Quarterly* 6 (Spring 1989): 57, 59. See also N. Catherine Hayles, *Chaos Bound: Orderly Disorder in Contemporary Literature and Science* (Ithaca, N.Y., 1990), esp. chap. 7.

19. Robert M. May, "Biological Populations with Nonoverlapping Generations: Stable Points, Stable Cycles, and Chaos."

20. Robert M. May, "When Two and Two Do Not Make Four," pp. 242–43.

21. William M. Schaffer, "Chaos in Ecology and Epidemiology," p. 233.

22. Ian Stewart, *Does God Play Dice?*, p. 22.

23. Brian Arthur quoted by M. Mitchell Waldrop, *Complexity*, p. 320.

24. Prigogine and Stengers, *Order Out of Chaos*, pp. 312–13.

25. Thomas Söderqvist, *The Ecologists*, p. 281.

26. Paul Colinvaux, *Why Big Fierce Animals Are Rare*, pp. 117, 135.

27. Botkin, *Discordant Harmonies*, pp. 6.

28. Ibid., p. 190.

29. See also Arthur F. McEvoy, *The Fisherman's Problem: Ecology and Law in California Fisheries, 1850–1980* (New York, 1986), pp. 6–7, 10, 150–51.

30. Edward O. Wilson, *Biophilia*, pp. 138–39.

31. Michael Soulé, "Conservation Biology and the 'Real World,'" pp. 3–5.

32. Wilson, *Biophilia*, p. 121.

33. Ralph Barton Perry, *The Thought and Character of William James* (New York, 1948), p. 175.

34. Stephen Toulmin and June Goodfield, *The Discovery of Time*, p. 17.

35. *Ibid.*, p. 232.

36. A contrary view of science and historicism is expressed in Werner Stark, *The Sociology of Knowledge* (London, 1958), pp. 164–67. Other useful treatments of the subject are Karl Mannheim's *Ideology and Utopia* (London, 1936); Robert Merton, "The Sociology of Knowledge," in *Social Theory and Social Structure* (Glencoe, Ill., 1949); and Peter L. Berger and Thomas Luckmann, *The Social Construction of Reality* (Garden City, N.Y., 1966), esp. pp. 1–18.

37. Arthur O. Lovejoy, "Reflections on the History of Ideas," p. 17.

38. Claude Levi-Strauss, *The Savage Mind* (Chicago, 1966), p. 263.

39. Karl Marx and Friedrich Engels, "Manifesto of the Communist Party," in *Basic Writings on Politics and Philosophy: Karl Marx and Friedrich Engels*, ed. Lewis S. Feuer (Garden City, N. Y., 1959), p. 10.

40. A new, "green" socialism has emerged in recent years, seeking to recover the neglected insights of Karl Marx and Friedrich Engels into the human–nature relation and to link the cause of protecting the earth with that of achieving a more equitable distribution of resources. The American journal *Capitalism, Nature Socialism*, edited by James O'Connor, is the best guide to this movement.

41. See Frederic Jameson, *Postmodernism: The Cultural Logic of Late Capitalism* (Durham, N.C., 1991), pp. 1–54. By "late capitalism" Jameson means a capitalism that is multinational in form, postindustrial in its sources of wealth, and dependent on modern communications and artificial intelligence for its operations. For another view of postmodernism and its relation to capital, see

David Harvey, *The Condition of Postmodernity: An Enquiry into the Origins of Cultural Change* (Oxford, 1989). Harvey believes that we are freeing ourselves not only from the logic of capital but also from the authority of objective science that has so long dominated our consciousness.

42. Edward Goldsmith, *The Way*, pp. 63–69. Goldsmith argues that, since all science is subjective and culturally bound, we are free to reject it and restore a more religious interpretation of nature. However, it is not clear why that restoration would be more valid or more immune to doubt than science.

43. John Muir, *My First Summer in the Sierra* (1911; repr. Boston, 1944), p. 157.