CHAPTER 6

Disturbance, the Flux of Nature, and Environmental Ethics at the Multipatch Scale

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The earth's environments and ecosystems are not fixed but vary over a wide range of space and time scales (Delcourt, and Webb 1982; see also fig. 6.1). At the scale of tens of thousands of years, the wobble of the Earth on its axis causes variation in the solar radiation received at the earth's surface, driving variation in climate. On shorter time scales, the Southern Oscillation of sea surface temperature in the eastern Pacific influences precipitation over large areas, causing floods at some locations and droughts at others. Change can be as gradual as the movement of continents and the uplift of mountain ranges and as abrupt as hurricanes and earthquakes. Because change is characteristic, present-day ecosystems must be understood in the context of their histories (Foster, Knight, and Franklin 1998), for example, in the context of ancient ice ages (Davis and Shaw 2001) and recent fires (Covington et al. 1999). The ubiquity of change raises the issues that are the subject of this chapter—the relationship of ecosystem dynamics, conservation management, and environmental ethics.

Among the most important sources of change at middle scales of space and time are natural disturbances (White and Jentsch 2001). These disturbances operate within the scales of our own lifespans and management choices, and a representative list of such events immediately suggests their relevance to humans, as well as to natural ecosystems: hurricane,

fire, flood, drought, avalanche, and volcanic eruption. While it is easy to view such disturbances as destructive (and they certainly have been viewed as punishments inflicted on the human race, as Belovsky points out in chapter 5 of this volume), these events are also part of the natural order—they have been recurrent, and many species are adapted to them. Natural disturbances can play a rejuvenating role in ecosystems, often increasing soil resources, plant growth, and reproduction of disturbance-dependent species. Many ecosystems depend on a pattern of disturbance for their composition, structure, and species diversity (White and Harrod 1997).

The importance of disturbance as a natural process in ecosystems has helped bring about the shift from the "balance of nature" paradigm to
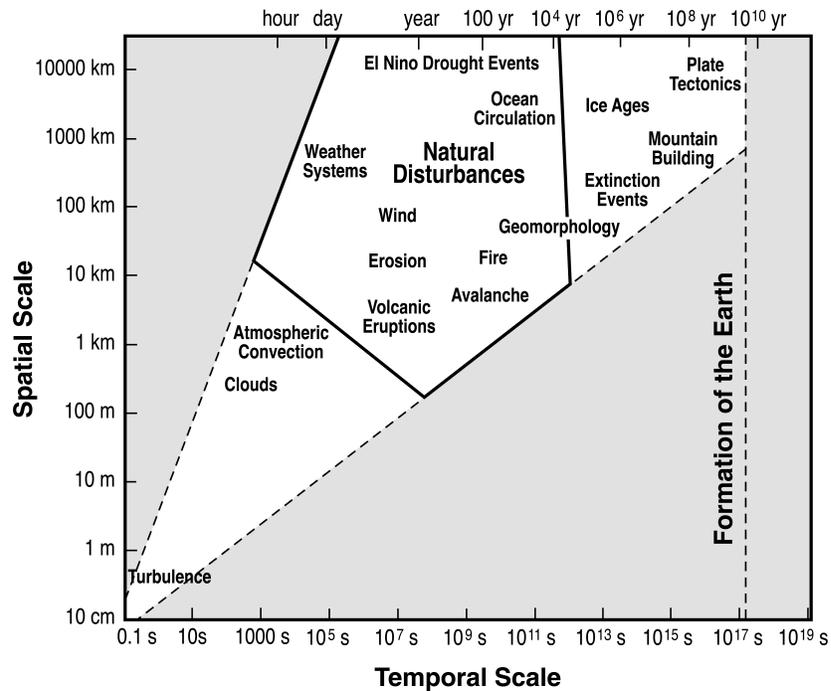

Figure 6.1. Variability in ecosystems occurs at a wide range of spatial and temporal scales. Natural disturbances occur over a broad area at middle space and time scales.

the "flux of nature" paradigm (Pickett, Parker, and Fiedler 1992; Callicott 2002). The balance of nature paradigm holds that ecosystems progress toward equilibrium states when free of human influence, that disturbances are external and rare, that integrated communities composed of the most adapted species occur in undisturbed conditions, and that such communities are self-perpetuating. The flux of nature paradigm holds that ecosystems are frequently disturbed in relation to the lifespans of the organisms present and thus are always in a state of response to previous disturbances, that disturbances are caused by factors both external and internal to the ecosystem, that species of early succession are just as "adapted" as species of late succession (albeit to different conditions), that communities are not tightly integrated, and that some communities are regenerated only through disturbance. The flux of nature paradigm suggests that we cannot find the basis for conservation management and environmental ethics in an eternal, equilibrium, unchanging, and prehuman natural condition. Where, then, can we find this basis?

In this essay, I present the basic concepts of disturbance ecology and an overview of recent findings in this field. I illustrate these concepts and findings through fire ecology in Great Smoky Mountains National Park, North Carolina and Tennessee, a landscape my collaborators and I have studied for over twenty years. I then return to questions about the flux of nature. The flux of nature is a nonequilibrium view, but the persistence of repeated dynamic sequences has, interestingly, suggested the possibility of larger scale, if locally dynamic, stability (White, Harrod, et al. 1999). The disturbance literature also raises questions about the human-nature relationship. How similar are human disturbances to natural dynamics? How do human and natural disturbances interact? How do humans affect the ability of ecosystems to respond to natural disturbances and climate change?

Throughout this essay, my assumption is that the conservation of biological diversity is a fundamental goal underlying environmental ethics. The premise of this assumption is that biological diversity supports human well-being, that species have rights to exist, or both (Callicott 1994). Nature supports human well-being by providing "ecosystem services" such as clean water, resistance to soil erosion, and pollination, and by providing direct benefits, both tangible (e.g., medicinal plants, fish and wildlife, and timber) and intangible (e.g., beauty and the sense of awe). In contrast, species-rights arguments justify conservation without

regard to human benefit. This approach is represented by the U.S. Endangered Species Act which, in theory, protects all species regardless of value to humans (although the act now also requires consideration of the costs of protection in human economic terms).

Biological diversity has been defined in two ways (White and Nekola 1992). The narrow definition of biological diversity is simply the number of species present. The broader definition recognizes that species diversity itself depends on genetic diversity within species, interactions between species, and the diversity of habitats and environments at larger spatial scales (Noss 1990). In this discussion, I have biological diversity in the broadest sense in mind. A fundamental proposition about diversity is that the resilience of nature—the ability to respond to future changes—is dependent on diversity. Genes, species, and habitat diversity all depend on a diverse array of conditions, some of them created by disturbance, and broaden the range of possible responses to future change. In the largest sense, diversity provides yet another ecosystem service—ability to respond to a world in flux.

Basic Concepts of Natural Disturbance

Definition

Disturbance has been defined in relative and absolute senses (White and Pickett 1985; White and Jentsch 2001). The relative definition defines disturbance relative to the normal dynamic domain of an ecosystem; thus some ecologists have reached the conclusion that "fire is not a disturbance in the prairie, absence of fire is the disturbance." The problem with this definition is that it assumes normal conditions can be defined. In fact, prairie fires are not all alike (there is considerable year to year and seasonal difference) and a single fire leaves behind a patchwork of varying effects. Given climatic variation, normalcy depends on the temporal scale on which it is assessed. Finally, the relative definition diverts attention from the measurable and absolute impacts of a given disturbance and hence is a poor starting point for studies of the mechanisms of disturbance response.

A widely used absolute definition is that disturbance is a "discrete event in time that disrupts ecosystem, community, or population structure

and changes resources, substrate, or the physical environment" (White and Pickett 1985, 7). The emphasis here is on the changes caused, although the degree of disturbance is relative to two characteristics: discreteness relative to the ecosystem under study and amount of change relative to the conditions of the pre-disturbance ecosystem. An easily grasped subset of the White and Pickett (1985) definition is that of Grime (1979): disturbance is a destruction of biomass. The destruction of biomass often opens space for new colonization, releases resources formerly contained in biomass, and creates new structures (e.g., arrangements of organic matter in the ecosystem). This definition applies to disturbance, whether natural, human, or the result of an interaction of human and natural factors.

Disturbance Regime

Disturbances vary tremendously—both within and between kinds of disturbance. This variation is described by the parameters of the disturbance regime under six categories: kind (for example, wind, fire, flood), spatial characteristics (for example, the size of the area affected and its position on the landscape), temporal characteristics (for example, frequency and season), specificity (for example, affecting larger plants, as wind does, or smaller ones, as ground fires do), magnitude (the amount of biomass affected), and synergisms (the interactions between disturbances, as when one disturbance, like wind damage, influences the occurrence of another disturbance, like fire) (White et al. 1999). Some characteristics are correlated: frequency is often inversely correlated with magnitude. Some authors have asked whether the highest magnitude disturbances (large, infrequent disturbances or LIDs) are a special disturbance case (Foster, Knight, and Franklin 1998; Romme et al. 1998 (see fig. 6.2).

Recent Disturbance Findings

Since the 1970s, there has been a burst of ecological interest in disturbance. This has resulted in the development of rich empirical detail about the way disturbances work. In the following paragraphs, I describe eight exciting areas of recent disturbance research.
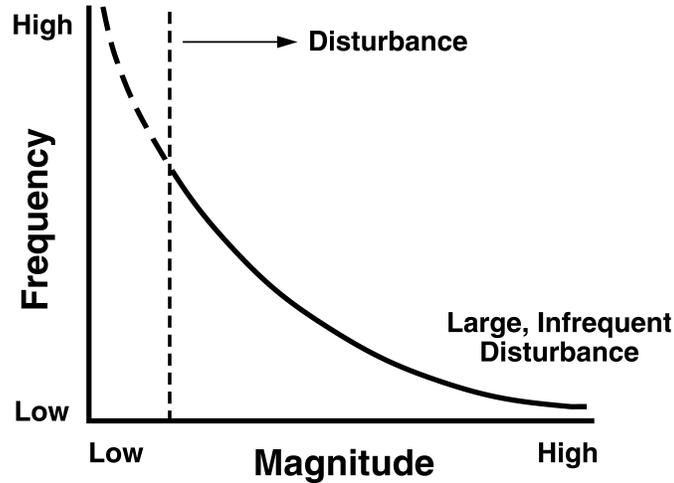
Figure 6.2. The inverse relationship of disturbance frequency and magnitude can be used to define "disturbance" and "Large Infrequent Disturbances" (from White and Jentsch 2001).

Disturbance and succession.   Ecologists at first saw disturbance as a mechanism for setting succession back to earlier stages. However, it is now clear that disturbance can have all possible effects on succession, depending on disturbance specificity—that is, whether disturbances affect all plants equally or have different effects depending on the disturbance property called specificity, namely, the size, age, or species affected (White, Harrod, et al. 1999). Disturbances that prevent the establishment of new or smaller individuals, like frequent fires in grasslands, hold succession in check. Disturbances that remove early successional dominants and release late successional species, such as wind disturbance in stands dominated by light-demanding trees, advance succession. Disturbances that remove dominant species and open up space for colonization of early successional species, such as crown fires in old stands, set succession back to earlier stages.

Some disturbances increase resource availability because they remove dominant competitors, thus reducing use of soil resources and light, and result in the mineralization of nutrients held in living biomass (Vitousek 1984). Succession in these situations is termed secondary succession

because soil remains as a substrate. In contrast, the erosional zone of debris avalanche scars may be left with no soil and low nutrient availability controlled only by the very slow process of rock weathering. Where no soil remains, succession is termed primary succession. Secondary successions are, of course, faster than primary successions because of the soils and resources present. Differences in successional starting point are differences in the legacy of the predisturbance ecosystem (see below) and are the result of differences in disturbance magnitude.

Disturbance-climate relations and regional synchronicity. Variation in climate causes variation in the incidence of disturbance (Clark 1988; Johnson and Larsen 1991; Swetnam 1993). For example, Swetnam and Betancourt (1990) showed that the total area burned in Arizona and New Mexico was approximately ten times higher in La Niña years than in El Niño years, with severe fire years approximately at six-year intervals. What is particularly important about this finding is that climate systems synchronize dynamics over large spatial regions—a bad fire year in one area of the Southwest is a bad fire year in all areas of the Southwest. This regional synchronicity causes stress to management agencies.

Ecosystem legacy. Disturbances vary in magnitude and thus in the kinds, amounts, and arrangement of organic matter and living organisms that are present and respond after the disturbance. The impact of the previous ecosystem on subsequent response is called ecosystem legacy (Swanson and Franklin 1992). Legacy consists not only of the organic matter, soil resources, and living organisms and their propagules, but also creates new structures, like pits and mounds from treefall, that influence response. Legacy is one key to ecosystem response to disturbance. The influence of legacy typically decreases with time since disturbance.

Synergisms. Disturbances interact. In many cases, repeat disturbances are likely, as when wind damage allows insect or fungal attack, or when insect damage increases the risk of severe fire (White, Harrod, et al. 1999). Sometimes one disturbance diminishes the chance of another, as when avalanche scars become fire breaks in mountain lodgepole pine forests or when a severe fire consumes so much organic matter that subsequent fire is unlikely (Veblen et al. 1994). Sometimes, the age and state of the ecosystem determine its vulnerability to disturbance such that dis-

turbance probability is initially low but increases with time. A feedback to time-since-disturbance would exert an ecosystem effect to make disturbances more regular in occurrence.

Natural disturbance and human influences.   Where once we conceived of presettlement North America as wilderness with minimal human influence, we now are discovering that Native Americans had substantial influence in many areas (Samuels and Betancourt 1982). Particularly with regard to fire, past human influence blurs the distinction between natural and human disturbances.

Landscape effects, pattern, and process.   Disturbance creates pattern in ecosystems (e.g., the distribution of disturbed and undisturbed patches), but the pattern of ecosystems also alters the process of disturbance (Turner, Gardner, et al. 1989). This effect can be either to increase or decrease disturbance rate. For example, an ecosystem that is fire prone but surrounded by fire breaks is less likely to burn (Veblen et al. 1994), but an ecosystem that is fire resistant may nonetheless burn if surrounded by ecosystems that allow intense fires to develop. In a particularly well developed example, Bergeron and Brisson (1990) have shown that islands in boreal forest lakes have different fire regimes than the surrounding mainland—they escape the infrequent but large and intense boreal forest fires but, particularly if they are high and attract lightning, have more frequent but lower intensity fires. As a result, red pine can only survive on the islands and not on the mainland.

Mechanisms of disturbance action and response.   The last several decades have produced a wealth of empirical details about species response to disturbance. Fire effects vary with the heat generated, flame height, and the speed of movement—thus we have to study fire in terms of specific and variable effects rather than as a single phenomenon (Ryan 2002). In terms of species response, Vogl (1974) suggested classifying species not as early or late successional, but rather, with reference to specific disturbance events, as increasers, decreasers, invaders, retreaters, and neutrals. In this sense, no single disturbance event (and no particular human management action) is good for all species. Too much disturbance can be as bad for biological diversity as too little; maintaining all species will require a mix of conditions.

Nonindigenous species. Recent research has shown that disturbances can increase the rate of invasion of alien pest species by opening up space and increasing resources. Because alien species invasion is one of the key threats to biological diversity, this complicates the job of managers seeking to reintroduce disturbance for native species. Some exotic species invaders can greatly change the disturbance regime. For example, alien trees in the Florida everglades can transpire more water into the atmosphere than the native plants, thus lowering the water table, drying organic matter, and making subsequent fires hotter (Bodle, Ferriter, and Thayer 1994). Introduced grasses in the American Southwest have altered the fire regime there (Billings 1990).

Disturbance, Fire, and Pine Ecosystems in Great Smoky Mountains National Park

Great Smoky Mountains National Park illustrates these concepts and the attendant questions for conservation management and environmental ethics. The park is about two thousand square kilometers and protects about five percent of the high mountain region along the border of North Carolina and Tennessee. Unlike western national parks, Great Smoky Mountains National Park was established through state purchases of private land. About one third of the park consists of forests not directly disturbed by people, and thus the park protects some of the finest old growth in the eastern United States. The remainder had been disturbed by farming or logging when the park was established in 1934.

Although the Smokies are famous for their old-growth forests, natural disturbances were always important, including wind, fire, flood, avalanche, and insect attack (Harmon, Bratton, and White 1983). Even old-growth forests are maintained as a diverse mix of species with different strategies through gap phase dynamics, that is, the dynamics that occur on individual patches after the death of a canopy tree (Busing and White 1993; White, MacKenzie, and Busing 1985).

Disturbances play many ecological roles in the Smokies. Some plant species cannot reproduce in the undisturbed forest, while at the same time other species depend on undisturbed areas. High species diversity requires both conditions. Second, some animal species move between and depend upon both disturbed and undisturbed patches. Black bears often den in the hollow parts of old-growth trees, yet also depend on

areas in which recent fires have stimulated berry production. Third, disturbances serve to connect terrestrial and aquatic ecosystems. Fire and wind disturbances in the forest influence the many characteristics of stream habitats: amount of woody debris, light availability, temperature, and nutrient status. These characteristics, in turn, influence stream organisms.

Fire was historically important in the national park, and its reduction, through fire suppression beginning about 1940, has resulted in changes to ecosystems (Harmon 1982; Harrod et al. 2000). The most fire-prone ecosystems, originally dominated by pine, have increased size and abundance of trees, shifted composition, and reduced diversity. Whereas managers have little influence on such disturbances as wind, flood, and avalanche, managers have had a large influence on fire. In the late 1990s, managers began the experimental reintroduction of fire to restore native species and ecosystems.

Historically, fire frequency varied with topography, increasing from moist valleys and lower slopes to ridges, but also decreasing from low to high elevations (Harmon, Bratton, and White 1983). Fires were thus most important on low and mid-elevation ridges. On these sites, fires ranged from frequent low intensity ground fires at 5–12 year intervals that killed understory seedlings and saplings but not overstory trees, to rare intense fires at 80–150 year intervals that caused high mortality and removed leaf litter and organic matter from the soil surface (fig. 6.3). Pine stands depended on both kinds of fire: the frequent ground fires kept out invading hardwoods but did not kill the overstory pine, and the intense fires allowed pine seedling establishment (which requires both light and open mineral soil without a covering of leaf litter) (White 1987). With fire suppression, size and abundance have increased in pine stands and composition is shifting to hardwood dominance, with a gradual decline in fire-tolerant species (Harrod, Harmon, and White 2000).

Disturbance interactions are evident in pine stands—intense fires are more likely in drought years (and thus in La Niña years) and on high woody fuel levels after southern pine beetle attack (White 1987). The beetle is a native insect that targets mature trees, so as postfire stands age they also become more vulnerable to beetle attack. Overstory trees die in a relatively short period of time and, as they drop branches and needles, produce high fuel loads.

Disturbances in pine stands also illustrate the many ways disturbances influence succession. Frequent ground fires killed hardwood seedlings
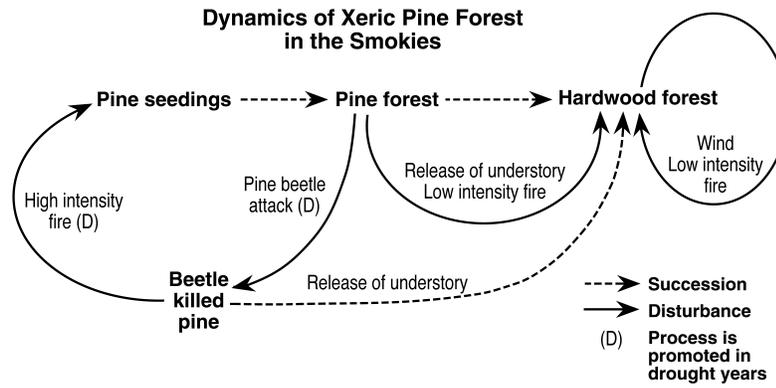
Figure 6.3. Pine and fire interactions on low and midelevation ridges in Great Smoky Mountains National Park (modified from White 1987).

and saplings invading pine stands from less fire-prone (moister) habitats, thereby holding succession in check. In the absence of fire, wind and the southern pine beetle are disturbances that advance succession because they kill the older pines and release understory hardwoods. Intense fires in older or beetle-killed pine stands set succession to an early stage and initiate pine regeneration.

Landscape pattern also probably influenced fire occurrence. Lower elevation pine stands are larger and closer together in the landscape. We can conjecture that one fire can spread from stand to stand and that many pine stands will have their origin from a single fire. At higher elevations, pine stands become more restricted to ridges. Isolated pine stands may each require a separate lightning strike, and such stands may burn in separate fires. However, regional droughts may cause all ridges to have high probability of burning in the same years.

Reduced fire frequency in the park has changed stand composition and structure, thereby altering legacy and response to management fires. For example, as the invading hardwoods age, they develop a thicker bark and become tolerant of fires that would have killed them in an earlier period (Harmon 1984). Thus, fire no longer decreases hardwood density and does not initiate pine regeneration. We may also be losing fire legacy in the form of the dormant seed bank of fire-dependent species. While

the jury is still out (only a few fires have been set in the Smokies, and only in the last few years), reintroducing fire alone may not restore diversity because suppression has altered forest structure.

As elsewhere, fire in the Smokies encourages invasion by invasive exotics, most noticeably the Japanese princess tree, *Paulownia tomentosa*. Managers seek to develop a fire-management plan that doesn't also promote invasive species. Research is now underway to see if the season or intensity of the fire affects how much princess tree invasion occurs.

Finally is the issue of naturalness (White and Bratton 1980; Sprugel 1991): is fire a natural process in the park and should the National Park Service reintroduce fire? Both Native Americans and European settlers burned the forest in the period before park establishment in 1934. The problem with treating fire as a purely human disturbance, however, is that human-set fires would also change the occurrence of natural fire. In some cases, human-set fires may have simply replaced natural fires that would have burned. However, human-set fires may have differed from natural fires in season and intensity. We do know that many plant species depend on fire (for reproduction and establishment), that these species have decreased during fire suppression, and that these species certainly predate the arrival of Native Americans some twelve thousand years ago, thus suggesting the importance of fire in the prehuman era. While our view of the past is qualitative and clouded, managers have proceeded to reintroduce fire to the park.

Scale, Disturbance, and Dynamic Equilibrium

One of the issues raised by disturbance ecology and fire ecology in the Smokies is the issue of spatial scale. Let's start by defining two scales (White and Jentsch 2001): the patch scale (the area affected by the particular disturbance event) and the multipatch scale (the landscape scale, which consists of many patches with various histories and times since disturbance) (see fig. 6.4). Patches that differ in age and disturbance history also differ in the species present, resource levels, and environmental factors. The multipatch scale thus contains many different species, resource levels, and environments. Indeed, disturbance is important because it creates an array of different age states and thus adds to the diversity of habitats present across a landscape. The multipatch scale is
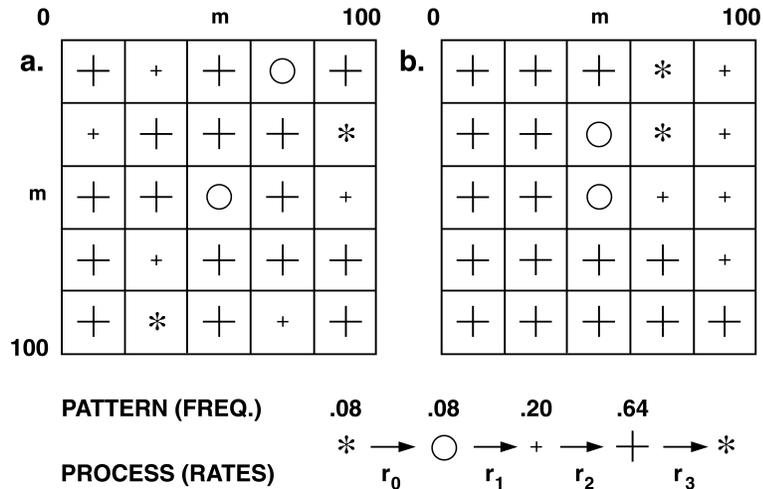
Figure 6.4. Diagrammatic representation of the patch and multipatch scales. Each square in the checkerboard represents one patch. Each patch can be in one of four states which are connected by a successional pathway (labeled r_0 to r_3). The patch states are as follows: * (dead trees), O (seed colonization stage), + (young trees), ✛ (mature trees). The two diagrams represent (a) patch types randomly distributed in space, and (b) patch types spatially clustered because the patch size of disturbance is larger than in (a).

critical to the maintenance of species diversity and to thinking about the role of disturbance—and, I will argue, is also critical to human ethical choice. In the Smokies, the multipatch scale encompasses many pine stands and the intervening stands of hardwoods on less fire-prone sites.

Recognizing the patch and multipatch scales allows us to ask not only about the dynamics of individual patches but also the properties of larger spatial scales. Consider the average biomass at the multipatch scale as an average across all patches (Shugart 1984). Younger patches have lower biomass than older patches. Though younger patches mature into older patches, thereby increasing biomass, older patches can be converted to younger patches through disturbance, decreasing biomass. The average across many independent patches will vary less through time than the values at the patch scale. As I describe below, the average through time need not be constant—it can exhibit what I will term bounded variation,

that is, a characteristic but ultimately limited variation about the average. The notion of dynamic stability is appealing because it suggests at large scales all species and successional ages are persistent despite great change at the patch scale. That persistence is obviously a characteristic conservation managers desire.

Even the early disturbance literature recognized the possibility of large-scale dynamic equilibrium (Watt 1947). For example, Heinselman's (1973) shifting mosaic concept was one in which the locus of disturbance shifts continually in space, but the total amount of land in any one successional age class remains constant. The term "patch dynamics" (Thompson 1978) was coined for the class of dynamics that included those within patches and the interaction among patches. Within patch dynamics, we distinguish two forms of potential equilibrium: quantitative and qualitative equilibrium (see fig. 6.5). Quantitative equilibrium (also called shifting mosaic or steady-state equilibrium) is a stricter form of equilibrium in which the distribution of age states at the multipatch scale is constant. Qualitative equilibrium (also called persistence equilibrium) is less stringent in that all species and stages are always present but may fluctuate considerably in abundance.

While studies of large spatial and time scales are not frequent, nature supplies examples of both quantitative (e.g., gap dynamics in old-growth forests of the Great Smoky Mountains) and qualitative (e.g., fire regime in the Yellowstone National Park) equilibrium (Turner, Romme, et al. 1993). However, superimposed on these dynamics, climate variation and human influence alters the underlying disturbance regimes. Hence, qualitative equilibrium is generally more likely than quantitative equilibrium and even qualitative equilibrium may be absent at time scales in excess of five hundred or several thousands of years.

Pickett and Thompson (1978) provided another conservation perspective on dynamic stability: spatial scale needed to support that stability. They argued that nature reserves had to be large enough to include a minimum dynamic area—if they were too small relative to the scale of disturbance, then the natural dynamic pattern would be lost. The nature reserve would be dominated by one or only a few age states and species of other states would be eliminated (Baker 1992). If a preserve is too small for natural dynamics, managers must attempt to manage disturbance in a way that all species and age states would survive. Since there is a cost to management, nature reserves ought to be large enough for minimal management intervention.
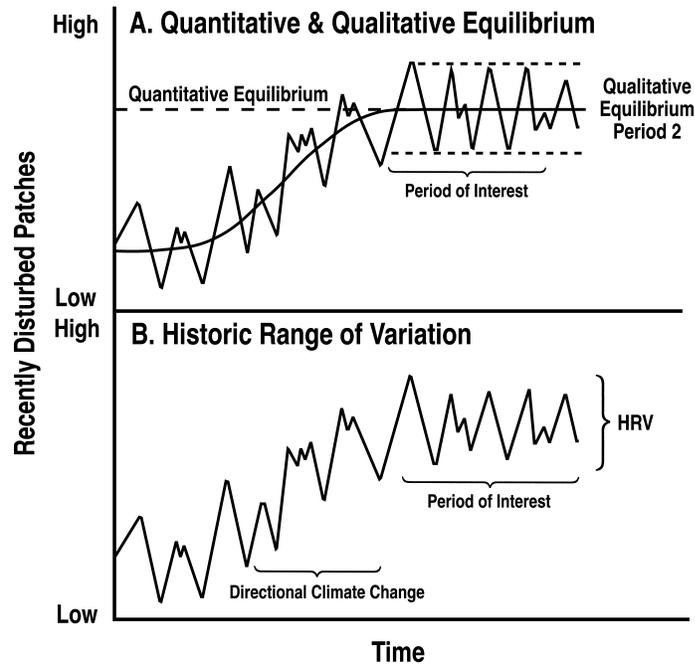
Figure 6.5. Patch dynamic equilibrium: (A) quantitative equilibrium and quali-tative equilibrium, and (B) the historic range of variation or range of natural variability (from White and Walker 1997).

In order to develop targets for ecosystem management, ecologists have sought to define the "historic range of variation" or the "natural range of variability" for particular ecosystems (fig. 6.5; see also Landres, Morgan, and Swanson 1999; White and Walker 1997). This corresponds to the concept of the qualitative equilibrium for particular landscapes—the range of conditions (spatial and temporal variability) that they would have possessed under historic disturbance regimes. Like the concept of qualitative equilibrium, this suggests that nature exhibits bounded rather than unconstrained flux, at least when disturbance regimes and climate do not themselves vary greatly.

In the Smokies, we know that the pine ridges are now outside the bounds of historic variation. Fire frequency is lower, tree size and abun-

dance are higher, composition is shifting, and fire-dependent species are declining (Harrod, Harmon, and White 2000). However, we have neither a long temporal record nor a very detailed picture of the spatial pattern and incidence of fire. In the absence of this information, managers are more likely to manage for species and habitat diversity than for natural process or historic range of variation. This becomes management for persistence of species and successional states and thus is implicitly a form of management for qualitative or persistence equilibrium. However, minimum dynamic area is certainly met in the Smokies. The park is large enough to contain many age states of the pine ecosystem at any one time.

The Challenge to Environmental Ethics from the Flux of Nature and Multipatch Scales

Flux causes two paradoxes in nature preservation: we seek to preserve ecosystems that must change and we often must extend the human hand, in the form of management, into ecosystems we want to see free of human influence (White and Bratton 1980). Fire management in the Smokies is an example of these paradoxes in that park establishment brought fire suppression and thus ongoing loss of pine stands. Fire management involves human-set fires, but what kind of fire (e.g., season and intensity) do we use? These paradoxes represent one of the challenges that the flux of nature brings to environmental ethics.

A related challenge is that, since nature is in flux, there appears to be no reference state by which to evaluate human-caused change. If ecosystems are dynamic and long-term climatic instability causes continual change, it is easy to view human-caused changes as just another and analogous source of change. A final challenge is represented by the multipatch scale: while a property of interest (biological diversity, in this case) has a behavior at the patch scale, it also has a behavior at the multipatch scale. Dynamic changes at the patch scale may not be correlated with dynamic patches at the multipatch scale. This makes observations at the patch scale potentially misleading and conclusions based on small-scale, short-term observations potentially wrong. Indeed, the behavior at the patch scale may, itself, be a function of patch dynamics at larger scales. How do we think about ethics at this scale, particularly when individual

actions at the patch scale cannot be judged on their own terms without reference to their contribution to the whole?

The Dilemma of Flux

Given my assumption that environmental ethics seeks behavior that conserves biological diversity, biological diversity itself becomes the metric for evaluating human and natural changes. Some human-caused changes may, in fact, mimic natural disturbances and support biological diversity. Ecologists have proposed that logging be based on natural disturbance patterns (Franklin and Forman 1987; Hansen et al. 1991; Bergeron et al. 2002). We also know that diversity depends on low intensity human cultural influence in some landscapes (e.g., the southern Appalachian grassy balds; see White and Sutter 1998; White 1984). At the other end of the spectrum, some natural changes may be so outside the adaptations of species that diversity is lost (e.g., the asteroid impacts that have caused mass extinctions in the past). In this regard, the intensity and scale of disturbance is more important than whether its cause can be unambiguously found in humans or nature. Unfortunately, the scale and intensity of human disturbances often does indeed lie outside the bounds of natural variability and the evolved range of responses of the biota. Fire in the Smokies is a good example: fire in the 1920s developed on huge pre-park clearcuts and, in this high rainfall region, resulted in so much post-fire soil erosion that some sites are still unforested seventy-five years after the fires. Clearly those fires were outside the natural range of variability in the park in terms of size and intensity. The general conclusion is this: we must not accept the analogy between natural and human disturbance uncritically but must ask about the absolute nature of that change.

The idea of qualitative equilibrium implies the recurrence of disturbance in space and time in a way that allows continued, though shifting, presence of all species and successional states in a patch dynamic state. Human action can result in a destabilization of this patch dynamic, by increasing or decreasing the frequency of disturbance (affecting which species can reproduce) and by increasing or decreasing the distance among patches (affecting which species are able to disperse among patches). If humans increase homogeneity (of age states) and decrease diversity, the range of possible species responses is reduced and the resili-

ence at larger scales decreases. In this sense, humans cause not just change, but, potentially, a reduced capacity of the ecosystem to respond to change, as well.

Multipatch Ethics

Because individual patches experience drastic changes even without human influence, the important outcomes of flux (e.g., diversity) cannot reside at the patch scale but are, rather, properties of the multipatch scale. Death and destruction at the patch scale can be part of birth and renewal at the multipatch scale. If we have an egalitarian view of species, then because different species require different patch conditions, we need a collection of patches in different states for all species to persist. The challenge to environmental ethics is that the ethical value does not reside at the patch scale, but at the multipatch scale.

Multipatch ethics can be illustrated in this way. Suppose that a student picks a native wildflower, for example an aster, and brings it to one of my classes. Was this a right or wrong action? At the patch scale, it can be argued the action was wrong because it deprives the plant of potential reproduction and robs the pollinator of a potential food source. However, asters, after long selection under various disturbances, often produce new flowering heads after loss. The reproductive contribution of a single group of flowers to the future of the population is low in this species. One could also argue that the aster improved the indoor environment—and enlivened the class. Given the premise that we want to maintain biodiversity, the more important question of rightness or wrongness is at the larger scales—if one student picks one plant out of a large population on a single day, the effect is small, but if thousands of students picked plants every day, the loss of reproduction, as well as the trampling of the soil, would lower future reproduction and the population would decline, ultimately until the species was extinct from campus. Clearly, the rightness and wrongness of the action can only be judged by sustainability at the multipatch scale.

We can extend this reasoning to an even larger scale. Suppose asters are eliminated from campus. This becomes less significant to biological diversity if asters still persist in wilder habitats beyond campus. The campus population might have a small impact on the future of the species.

Also, the campus once had more populations than it does now—my classroom facility itself replaced some native habitat and many species with it, yet classrooms are clearly needed if we are going to train conservation biologists. The answer to these dilemmas lies at broader scales: a balance must always be struck between human effects at the patch scale and the persistence of biological diversity at larger scales. There are biological constraints, determined by the tolerance of the species present to habitat loss and fragmentation, as well as tolerance to direct impacts on the quality of remaining habitats (e.g., pollution). Further, it is clear that the greater the number of populations (e.g., of asters) the more resistant the species is to extinction. It is also clear that humans rarely have considered the patch versus multipatch balance until populations have been so reduced that the species is on the verge of extinction. So, what is the right scale and the right balance? The answers to these questions are likely to be different for different species and different ecosystems and different if we consider long-term climate change versus short-term persistence. We simply need to collect the information needed to answer the questions in different circumstances.

Multipatch ethics suggests that ethics of individual, patch-scale action is less important than the ethics of collective action at the multipatch scale. It is possible for an action at the patch scale to be judged on its own terms—whether the intensity of disturbance at the patch scale exceeds the tolerance and response of species that respond to disturbance—but it is at the multipatch scale that this evaluation is most critical. Because the species have a finite range of tolerances as the result of their evolutionary history, there is likely to be a strong historic or "precedence" component to response. Thus, from an ethical point of view, we must also ask questions such as: Are human actions inside or outside the historic range of variation? Are they inside or outside the tolerances of species present?

Synthesis: Society and the flux of nature

What principles should we take away from this discussion? I propose three. First, we should accept natural disturbances as important forces and support their restoration where needed. Second, we should not put human life and property in disturbance's way—we should avoid building on earth's shifting sands, eroding and migrating coastlines, steep un-

stable slopes, floodplains, and fire-prone sites. Third, we should conserve the ability to respond to dynamics itself by conserving diversity. Ultimately this is based on the proposition that resilience derives from diversity.

The management of nature for dynamics may seem a daunting task. What if we can't conserve nature in a way that supports a dynamic equilibrium? Can we substitute human disturbances? How right do you have to get the disturbance regime (White and Walker 1997)? How tolerant are species and ecosystems to some variation in disturbance and dynamics? What scale of conservation is critical? These are important questions and, although I suspect that species and ecosystems are moderately tolerant, we do not have good answers to these questions in a quantitative sense. Our job, however, is not to complete the job for all time—indeed, future climatic change is inevitable. Rather, our job is more like the passing of a baton rather than the completion of a race. Even when we can't solve all conservation problems for all time, we must remember that our job is to pass ecosystems along in the best state we can. One fundamental goal is expressed by Leopold's First Law of Tinkering—we must save all the pieces. This translates to saving variation in species and habitats and thus the processes, such as disturbance, that create the conditions for that variety. This rests on the dictum that diversity itself is a resource for future adaptation and future response to change.

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