Peter S. White [1] **and** ***Anke Jentsch*** [2]

DEVELOPING MULTIPATCH ENVIRONMENTAL ETHICS: THE PARADIGM OF FLUX AND THE CHALLENGE OF A PATCH DYNAMIC WORLD

[1]Department of Biology, Campus Box 3280, University of North Carolina at Chapel Hill,
Chapel Hill, North Carolina 27599-3280, UNITED STATES OF AMERICA
Email: peter.white@unc.edu

[2]Centre for Environmental Research, UFZ Leipzig-Halle and University of Bayreuth,
Permoserstraße 15, 04318 Leipzig, GERMANY
Email: anke.jentsch@ufz.de

Abstract

The paradigm of flux poses a challenge to environmental ethics: 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 continued change, it is easy to view human caused changes as just another and analogous source of change. A related challenge is represented by the issue of sustainability at the landscape or multipatch scale: while a property of interest (e.g. biological diversity) has a behavior at the local or patch scale, it also has a more important behavior at a multipatch scale. Dynamic changes at the patch scale contribute to, but can be uncorrelated with, dynamic changes at the multipatch scale. This makes observations at the patch scale potentially misleading and conclusions based on small-scale, short-term observations potentially wrong. How are ethics at larger scales thought about, particularly when individual actions at the patch scale cannot be judged on their own terms without reference to their contribution to the whole? 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. Just as a shift from the “balance of nature” paradigm to the paradigm of flux is seen, there is a need to focus ethics on sustainability: the capacity for dynamic balance at multipatch scales. A human-landscape relationship is sought that allows a dynamic system of diverse elements to retain its capacity to adapt. Ultimately this is based on the proposition that resilience itself, in turn, depends on diversity.

Key words: Disturbance, patch dynamics, the paradigm of flux, sustainability

1 Introduction

The authors are plant ecologists who study the dynamics of natural and semi-natural ecosystems. In this work, conservationists and government land managers often ask the question: What is the reference state that is the goal for conservation, restoration, and management? In essence they are asking a question that involves both values (and therefore environmental ethics) and the understanding of nature. In North America, pristine, human-free, wilderness represents one commonly accepted reference state. In Europe, wilderness has not been such an important issue and cultural landscapes have been more important in conservation. This is because most of current biodiversity in Europe is due to centuries of human influence. Despite these differences, this work has led to an understanding that is believed to be essential to the discussion of environmental ethics.

The focus is on disturbance (i.e. both natural and human) because it often raises controversial ethical issues (White and Bratton 1980; Jentsch et al. 2003; White 2005). This is because disturbance can be locally destructive and yet be essential to conservation, contributing to species persistence, ecosystem function, and stability at larger spatial scales.

This perspective on environmental ethics could be applied to any societal goal for land management. For example, forests are managed for productivity, water supplies, beauty, recreation, and the native diversity. These goals represent different values. The purpose is not to discuss or rank these underlying values. In this paper the focus is on biological diversity. Biological diversity is contingent on time and place and cannot be maximized or specified in the abstract. Biodiversity is a common currency for ecologists and nature conservation and also supplies the raw material for future changes and adaptational responses. It is taken as axiomatic that diversity has four values: (1) utilitarian value (e.g. products, spiritual well being, and ecosystem services that support environmental quality), (2) intrinsic value, (3) functional value (i.e. species contributions and interactions that form the basis of ecosystem function), and (4) adaptational value (i.e. the ability to change and adapt to unknown future states is first and foremost a product of diversity –the higher the diversity, the greater the range of future possible states– see Beierkuhnlein and Jentsch 2004; Figures 1 and 2).

The objective of this paper is to discuss the implications of ecosystem dynamics and scale for environmental ethics (White 2005). This perspective will be developed from patch dynamics and a collection of patches is called the “multipatch” scale. The multipatch scale can be applied at the scale of a mosaic of stands in a forest to the global scale. Although many decisions are (and must be) made at small scales, ethical concerns should connect those small scale decisions to ecosystem dynamics at larger scales. This will begin with a review of ecosystem dynamics and the “paradigm of flux.”

2 The Paradigm of Flux

The earth’s environments are in flux on many time and spatial scales (Delcourt et al. 1982; Figure 3). Continents drift; ice ages come and go; species arise, evolve, and become extinct; and windstorms, floods, avalanches, droughts, and fires are not the act of gods beyond understanding, but events that have always occurred. Some species are adapted to and require the conditions produced by the sudden destruction of biomass and would disappear without these recurrent events. Ecosystems undergo cycles produced by disturbances, but they also move along trajectories over longer

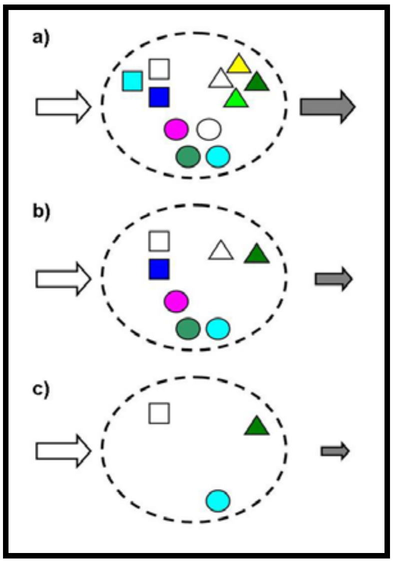

Figure 1. The Diversity Effect. The symbol shapes represent different functional types; the colors represent different species within a functional group. The size of the arrows represents ecosystem function with environmental variation. The Diversity Effect says that the more species there are in an ecosystem, the greater the ability to continue basic ecological functions like productivity. If there is a pure effect of diversity, then (a) has greater function than (c) (with (b) intermediate) because, although all functional types persist in all cases, diversity per group is highest in (a) and lowest in (c).

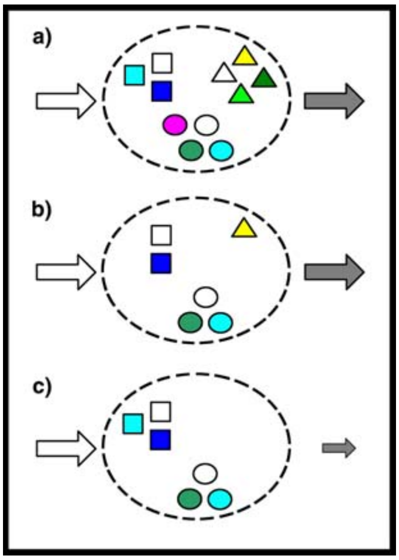

Figure 2. The Redundancy Effect. The symbol shapes represent different functional types; the colors represent different species within a functional group. The size of the arrows represents ecosystem function with environmental variation. The Redundancy Effect says that the number of species is less important to function than the number of functional types represented. In (a) all functional types and species are present and in (b) all functional groups, but fewer species per group are present. Nonetheless, because all functional groups are represented in (a) and (b) they have the same function (size of arrow). Group (c) has reduced function because of loss of functional types, not because of loss of species since it has the same number of species as (b).

time scales with climate change, soil development, species evolution, change in social and economic development, and change in human values.

The idea of a world in flux has been formalized as the “paradigm of flux” (Pickett et al. 1992). In the last several decades this new paradigm has replaced the old one, formalized as the “paradigm of balance.” The paradigm of balance suggested that natural systems were evolved to be a harmonious machine of essential cogs and wheels. However, it is known that the importance of individual species varies, that some functions overlap among species, and that the very character of ecosystems has changed through time, for example, from the Lower Plant dominated forests that produced the coal beds to the Higher Plant forests of today.

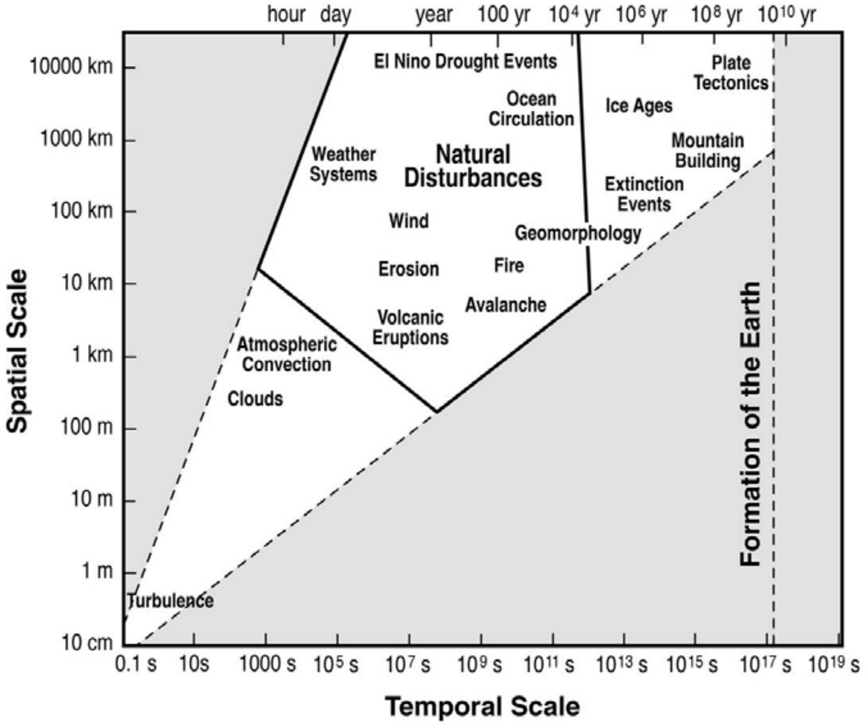

Figure 3. The environments of the earth show variability on a wide range of temporal and spatial scales (White 2005). Natural disturbances occur on a mid-range of temporal scales and at moderate to large spatial scales.

The paradigms of balance versus flux have been discussed in many contexts, including the equilibrium (balance) or non-equilibrium (flux) nature of ecosystems (Sprugel 1991; Baker 1992). Equilibrium is an easier criterion for ethical choice. Non-equilibrium represents a challenge to ethical choice because a clear reference state is absent.

The paradigm of flux thus opens many questions. If there is no "best," harmonious, and eternal condition of nature, what is the reference state for conservation? How can it be claimed, based on reference to a naturally disturbed nature, that any human action, no matter how extreme, is wrong because it is somehow "unnatural"?

These questions will be addressed by developing a framework that enlarges the discussion from state to process and incorporates larger scales of time and space. Studies of disturbance dynamics are used to develop this perspective and also to extend it here to humans as actors in the system.

3 Disturbance and the Multipatch Perspective

Disturbances in forests range from individual tree deaths and selective cutting, to larger patches caused by large scale logging, wind, pathogen attack, or fire. 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; White and Jentsch 2001). This perspective applies to both natural and human disturbance.

Disturbances vary tremendously, both within and between kinds of disturbance. This variation is described by the parameters of the disturbance regime under six categories (White and Jentsch 2001): kind (e.g. wind, fire, and flood), spatial characteristics (e.g. the size of the area affected and its position on the landscape), temporal characteristics (e.g. frequency and season), specificity (e.g. does it affect larger plants, as wind does; or smaller ones, as ground fires do), magnitude (e.g., the amount of biomass affected), and synergisms (i.e. the interactions between disturbances, as when one disturbance, like wind damage, influences the occurrence of another disturbance, like fire). Some characteristics are correlated: frequency is often inversely correlated with magnitude such that large and intense disturbances are rare (Foster et al. 1998; Romme et al. 1998). Synergisms are difficult to fully assess and document, but are particularly interesting because they represent the interplay of internal and external causes of additional disturbances. In addition, synergisms arise from human interactions with natural disturbances.

Humans often perceive disturbance as a single event occurring at a certain location in space. Ecologists refer to the disturbed area as a patch. Disturbances may have connotations of being negative; however they also cause positive changes. Destruction of biomass at the patch scale often increases resource availability and thus regeneration and growth rates. Individual patches develop through a series of stages as biomass re-accumulates. Speed of change is often most rapid at first and then slows, but the absolute speed varies with the characteristics of the disturbance and the ecosystem. Some species increase after disturbance, some decrease (and increase again with time since disturbance), and some are unchanged. Many wildlife species move among and use different patches in different age states for foraging or breeding. Their critical habitat thus consists of a mosaic of patches.

The multipatch scale or landscape scale is the scale at which there are many patches with various histories and times since disturbance (Figure 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, speeds of development, and environments. Indeed, disturbance is important because it creates an array of different age states and thus adds to the diversity of environments, successional pathways, and rate of successional change across a landscape. The multipatch scale is critical to the maintenance of species diversity and to thinking about the role of disturbance, and it will be argued that it is also critical to understanding sustainability and human ethical choice.

Figure 4. An aerial view of a Canadian landscape after a light snow, showing patchiness created by both agricultural disturbance (e.g. recently plowed fields are dark, unplowed fields are snow covered) and natural disturbance (e.g. the meandering river with its many bends and cut-off oxbow lakes.

Recognizing the patch and multipatch scale allows one to ask not only about the dynamics of individual patches, but also properties of larger spatial scales. Consider the average biomass at the multipatch scale as an average across all patches, regardless of patch age (Shugart 1984). The average across many independent patches will vary less through time than the values at the patch scale. The average through time need not be constant, for example, it can exhibit bounded variation, that is, a characteristic, but ultimately limited, variation about the average.

Even the early disturbance literature recognized the possibility of large scale dynamic equilibrium (Watt 1947). For example, the 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 (Heinselman 1973). The term “patch dynamics” was coined for the class of dynamics that included the dynamics within patches and the interaction among patches (Thompson 1978; Pickett and White 1985). Within patch dynamics, two forms of potential equilibrium are distinguished: quantitative and qualitative equilibrium (discussed in White and Jentsch 2001; Figure 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.

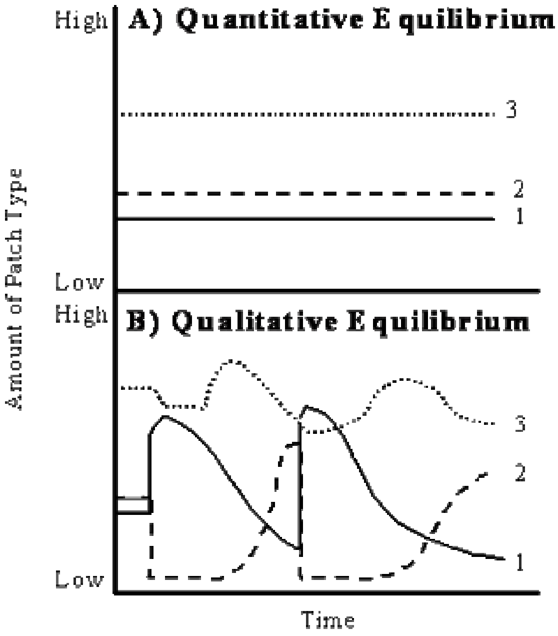

Figure 5. A. Quantitative equilibrium describes a situation in which the relative amounts patch types (e.g. successional stages or ages) are constant over time.
B. Qualitative or Persistence Equilibrium in which there is considerable variation in the amounts of the patch types over time, but all persist in the landscape. There are three successional stages or ages depicted: late succession (3, dotted lines), mid-succession (2, dashed lines), and early succession (1, solid lines).

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 (Landres et al. 1999). This corresponds to the concept of the qualitative equilibrium for particular landscapes, the range of conditions (i.e. 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. This offers the possibility to refine ethical decisions to maximize the potential for change within the restrictions of qualitative equilibrium, meaning the bounds of variation of a particular system.

While studies of large spatial and temporal scales are not frequent, nature supplies examples of both quantitative and qualitative equilibrium. 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. Qualitative equilibrium may be more desirable because bounded variation integrates dynamic fluctuations of many kinds.

The phenomenon of dynamic stability imposes a minimum spatial scale for ethical decisions. For example, nature reserves have 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 (Pickett and Thompson 1978). The nature reserve would be dominated by one or only a few age states and species of other states would be eliminated. 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. This is also true for other issues in ethical decision making. A minimum scale is necessary for evaluation of consequences although potential actions of decision makers take place at the patch scale.

This discussion raises the issue of scale effects and sustainability in ecosystem dynamics; this is the next topic, but first note here that the "paradigm of flux" has become at larger spatial scales, ironically, a "paradigm of dynamic equilibrium" and, in some sense, leads back to a concept of "nature in balance," though it is, at best, a rough large scale stability based on small scale dynamics. Of course, ecosystems are also on an overall trajectory due to clanging climates, soil development, and, of course, human influence. Thus at larger temporal scales, one finds oneself back in "a paradigm of flux."

4 Sustainability from a Multipatch Perspective

Although each patch in a landscape mosaic goes through a dramatic series of changes (e.g. from low biomass to high and from dominance by one set of species to another set) a collection of patches exhibits less overall fluctuation. It can then be asked: what conditions are necessary for dynamic stability?

In answering this question, consider two extremes of species dependence on the dynamic mosaic: those species that require disturbances for regeneration and those that accumulate with time since disturbance. Disturbance dependent species are often fast growing, early reproducing, and short-lived species and those that accumulate with time since disturbance are often slow growing, late reproducing, and long-lived species. Species that require disturbances for regeneration require that disturbances have a minimum frequency in time and space. Disturbances must occur before the species has ceased to reproduce and must be located within the dispersal distances that characterize the species (although such adaptations as a pool of dormant seeds in the soil can extend this period beyond individual life span). The disturbances must be of the appropriate intensity to provide the conditions (i.e. high resource abundance, low competition) that these species require for regeneration. Species that accumulate between disturbances require that there is enough time without disturbance for maturation and regeneration.

Landscapes have other sources of heterogeneity than disturbance, namely, variation in topography, substrates, and human influences. Thus, it is not necessary to expect that disturbances and patch types will occur with the same frequency across the landscape. Some places may be more vulnerable to repeat disturbances and others may be more protected. Nor is it necessary that there be a strict quantitative equilibrium in disturbance frequencies or patch distributions. It is only necessary that the mosaic contain the range of patch types and the frequency of disturbances sufficient to maintain the species and the repetition of the characteristic dynamics.

The ability to respond to disturbance, to retain all species, and to repeat dynamic patterns is the quality of resilience, also defined as the ability to absorb disturbance without change in the system (Turner et al. 1993). Resilience implies that there are thresholds in the ecosystem. Below the threshold, the landscape is resilient; if disturbances exceed the thresholds in their spatial or temporal characteristics, the ecosystem will change qualitatively. Human intervention, then, is best judged relative to ecosystem specific thresholds. Unfortunately, there is not a good understanding of these thresholds, nor how they vary for different ecosystem characteristics. However, these thresholds determine a systems ability to go on changing within the bounds of dynamic stability. As long as human action does not interfere with the systems ability to go on changing, such action is considered within the bounds of ecological sustainability.

It is now argued that sustainability is fundamental to ethical decisions.

5 Developing a Multipatch Environmental Ethics

Since individual patches experience drastic changes even without human influence, the important outcomes of flux (e.g. diversity) do not reside at the patch scale, but are, rather, a property of the multipatch scale and dynamics at this scale. Because different species require different patch conditions, a collection of patches in different states is needed for all species to persist. The challenge to environmental ethics is that the ethical value at the patch scale needs to be evaluated, in part, in the context of the multipatch scale.

To transfer these ideas to even larger scales (e.g. the continental scale), each country may have a different responsibility and different criteria for ethically correct management of their “patch” of the world in an ecologically sustainable way. Restrictions on scaling up disturbance are given by the scales of biotic mechanisms for adaptation to change, such as ecological plasticity, dispersal, and migration (Jentsch and Beierkuhnlein 2003). As soon as these biotic mechanisms of adaptation are exceeded by the extent or speed of change brought about by human action, the system is not within sustainable dynamics and the ability for the system to go on changing is reduced.

It is possible for an action at the patch scale to be judged on its own terms. For example, the intensity of human disturbance at the patch scale may exceed the tolerance and response of species that respond to disturbance. The introduction of novel and long-lived toxins is another human effect that can obviously be evaluated at the patch scale. However, it is at the multipatch scale that issues of sustainability are most critical. It is at this scale that the essential right or wrong exists: resilience, retention of elements, and continued ability to respond to disturbance are a property of the collection of patches rather than the individual patch.

Each kind of landuse and each proposed use of a particular tract of land has potentially negative impact, but the real issue is at larger spatial scales: not whether an individual action at a particular place is right or wrong, but how these add up at larger scales. The issue becomes more a question of amount than absolute right or wrong judged at small scales of time and space. Thus, there is a scale dependence in ethical evaluations. There is greater uncertainty at small scales, and it is more reasonable to make judgments at large ones. It is challenging, however, because landuse choices are focused on actions at smaller scales. The maximum scale is given by biotic mechanisms of adaptation to change.

The human context also changes the context for ethical decisions. The human species is also on a trajectory –to a larger population size and more total impact. This reduces the space available for ecosystem dynamics at the multipatch scale. This has two implications: that the ability to find solutions at large scales is being reduced and the ethical imperative is therefore shifting to smaller scales. Decisions at small scales that might have once been tolerated as part of a larger landscape are now causing landscapes to approach their thresholds that will change overall ecosystem behavior. Because of the need for a multipatch perspective and the changing implications of change at the patch scale through time, decision makers are often thrown into dilemmas.

6 Conclusion

In this paper, the ethical basis for the conservation of biological diversity is addressed in the context of two inescapable facts: (1) natural ecosystems were characterized by recurrent disturbances and thus flux rather than stasis (see also discussion in White 2005) and (2) humans cannot be considered as external to the ecosystems on which biological diversity depends (indeed, it is believed these ideas apply to both of the global areas represented by the authors, the largely natural ecosystems of parts of North America and the cultural ecosystems of Europe). Rather than using nature and human-free equilibrium as the ultimate basis of ethical right and wrong, it is proposed that a focus be placed on the concept of sustainability. Sustainability is then applied to the problem of the long-term persistence of biological diversity.

The importance of disturbance suggests that ecosystem dynamics must be accepted, not resisted. Indeed, the suppression hypothesis (see discussion in White and Jentsch 2001), developed for fire ecology, suggests that by attempting to reduce natural disturbance risk in the short-term, disturbance intensity will sometimes increase in the long-term. In general, care should be taken in placing human life and property in disturbance prone ecosystem contexts. Restoration of dynamics should also be supported, such as the return to free flowing rivers and natural fire regimes. Some species should also be expected to be self-sustaining only at larger scales (e.g. those species dependent on disturbance or on a mosaic of various patch age states). It should also be expected that there are limits to the resilience of ecosystems. This is all the more challenging since decisions must be made in the absence of complete knowledge. This suggests both the importance of the precautionary principle and the need to pass on the highest possible diversity to the next generation (Principle 4, below).

The ethic of sustainability for biodiversity consists of four principles:

Principle 1. Future states and production of utilitarian value (e.g. whether products, spiritual well being, or ecosystem services) depends on diversity because diversity is the raw material of response to change.

Principle 2. Sustainability and resilience are the essential issues, rather than change at small scales. This suggests a larger scale approach to ethics. Sustainable dynamics and resilience describe the quality of continuing to be dynamic at shorter time scales and to exhibit adaptational change at longer time scales. These qualities preserve the ability of ecosystems to go on changing, but it is not unlimited change. Rather it is change bounded by tolerances and functional responses of the species present.

Principle 3. Humans are a species in the patch mosaic and their actions should also be considered from a multipatch perspective, with sustainability being the criterion for ethical right and wrong at this scale. This introduces the idea that it is not only the quality of human effect at the patch scale that is important, but the amount and impacts on the multipatch mosaic. While some human choices can be evaluated exclusively at the patch scale, others suggest that patch scale decisions should be made within the perspective of ethics at the multipatch scale. In any case,

Principle 4. Understanding ecosystem dynamics, trajectories, and thresholds is a challenging problem. It is notable, though, that each generation can address only a narrow window in time and cannot resolve future uncertainties nor devise the perfect solution for all future conditions. In this sense, the task of each generation is more like a relay race than an individual race. Each generation must pass the baton to the next; in passing on the highest possible remnant of the original diversity, they also pass along the greatest number of future options.

References

Baker, W.L. 1992. The landscape ecology of large disturbances in the design and management of nature reserves. Landscape Ecology 7: 181-194.

Beierkuhnlein C. & Jentsch, A. 2004. Ecological importance of species diversity. A review on the ecological implications of species diversity in plant communities. In: Henry, R (ed.): Plant diversity and evolution: Genotypic and phenotypic variation in higher plants. CAB International, Wallingford. pp. 249-285.

Delcourt, H.R., Delcourt, P.A. & Webb III, T. 1982. Dynamic plant ecology: The spectrum of vegetation change in space and time. Quarterly Science Review 1: 153-176.

Foster, D.R., Knight, D.H. & Franklin, J.F. 1998. Landscape patterns and legacies resulting from large, infrequent forest disturbances. Ecosystems 1: 497-510.

Heinselman, M.L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quaternary Research 3: 329-382.

Jentsch, A., & Beierkuhnlein, C. 2003. Global climate change and local disturbance regimes as interacting drivers for shifting altitudinal vegetation patterns in high mountains. Erdkunde 57 (3): 218-233.

--, Wittmer, H., Jax, K., Ring, I. & Henle, K. 2003. Biodiversity: Emerging issues for linking natural and social sciences. Gaia 2: 121-128.

Landres, P.B., Morgan, P. & Swanson, F. J. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications 9: 1179-1188.

Pickett, S.T.A. & Thompson, J.N. 1978. Patch dynamics and the design of nature reserves. Biological Conservation 13: 27-37.

-- & White, P.S. (eds.). 1985. The ecology of natural disturbance and patch dynamics. Academic Press, New York. 472 p.

-- Parker, V.T. & Fiedler, P.L. 1992. The new paradigm in ecology: Implications for conservation biology above the species level. In: Fiedler, P.L. & Jain, S.K. (eds.). Conservation biology. Chapman Hall, New York. pp. 66-88.

Romme, W.H., Everham, E.H., Frelich, L.E., Moritz, M.A. & Sparks, R.E. 1998. Are large, infrequent disturbances qualitatively different from small, frequent disturbances? Ecosystems 1: 524-534.

Shugart, H.H. 1984. A Theory of Forest Dynamics: The ecological implications of forest succession models. Springer-Verlag, New York. 278 p.

Sprugel, D.G. 1991. Disturbance, equilibrium, and environmental variability: What is “natural” vegetation in a changing environment? Biological Conservation 58: 1-18.

Thompson, J.N. 1978. Within patch structure and dynamics in Pastinaca sativa and resource availability to a specialized herbivore. Ecology 59: 443-448.

Turner, G.M., Romme, W.H., Gardner, R.H., O‘Neill, R.V. & Kratz, T.K. 1993. A revised concept of landscape equilibrium: Disturbance and stability on scaled landscapes. Landscape Ecology 8: 213-227.

Watt , A.S. 1947. Pattern and process in the plant community. Journal of Ecology 35: 1-22.

White, P.S. & Bratton, S.P. 1980. After preservation: The philosophical and practical problems of change. Biological Conservation 18: 241-255.

-- & Jentsch, A. 2001. The search for generality in studies of disturbance and ecosystem dynamics. Progress in Botany 62: 399-450.

--. 2005. Disturbance, the flux of nature, and environmental ethics at the multipatch scale. In: Lodge, D. &. Hamlin, C. (eds.). Religion and the new ecology: Environmental prudence in a world in flux. University of Notre Dame Press, Notre Dame. [PAGE CITATION]