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Restoration as an ecosystem process: implications of the modern ecological paradigm

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The problem: what do modern ecological principles have to say to restoration?

The goal of ecological restoration ostensibly is to return ecosystems to a state or condition from which they can be self-sustaining thereafter. Consequently, the fundamental problem we will address in this chapter is the question, how can ecological principles inform restoration? Such principles include the concepts used to analyse ecological systems, the role that history plays in ecological systems, the nature of the processes that are included in our view of nature, and the models we use to understand it. Unfortunately, ecology has more than one perspective that influences our thinking. We will argue that one set of principles, what we shall refer to as the contemporary paradigm, is the only valid approach for restoration. To set the stage, let us consider some alternatives. For instance, how we think of ecosystems affects restoration, and to illustrate this consider the question: are ecosystems strictly biogeochemical processing or productivity factories, or do they include a site or collection of species? A second set of important questions concerns the nature and impact of history: what role does history play in the current state of the system of interest? Is the past trajectory of a system a regular course of stages, or is it an idiosyncratic series of events? Finally, how we see ecological processes can affect restoration. To what extent are the processes within ecosystems congruent with the system boundaries and do such processes direct systems to well-defined endpoints?

Because answers to such questions form the basis for restoration, it is important to have an account of the current understanding of the issues they raise. How these questions might be answered has changed and evolved over the last few decades (Simberloff 1980; Botkin 1990; Pickett, Parker, & Fiedler 1992). Restoration can benefit from changes in ecological thinking (Pickett & Parker 1994) and we see features of modern ecology that are significant for restoration ecology.

The first aspect of modern ecology of value to restoration ecology is the return to a broader perspective of the ecosystem. The ecosystem has been viewed, by many ecologists and people engaged in using ecological principles to manage, conserve, and restore nature, as a narrow concept suitable only for understanding energy or nutrient flux and mineral cycling. We will show below how the more inclusive concept of the ecosystem can help improve restoration practice.

The second feature of modern ecology of relevance to restoration is the paradigm of the discipline. A new paradigm suggests general principles that can be useful in the application of the science. A paradigm is nothing more than the viewpoint and set of background assumptions of the discipline (Margolis 1993). The world view includes those most general principles that structure the science, as well as the judgements about what areas and questions are of interest, how to approach those questions, and what constitutes a valid answer. Here, we will be concerned with the general principles that the paradigm summarizes.

A problem in applying ecological principles is how to relate the general principles, which must suit a wide variety of ecological conditions and environments, to the idiosyncrasies of specific sites. Recognizing the important role of history and the specific conditions that influence a site, some practitioners have despaired of effectively applying ecological principles in 'real world' situations (Shrader-Frechette & McCoy 1993). However, ecology is beginning to deal effectively with the historical nature of its subject-matter (e.g., Davis 1986). 'Contingency' is the label we will use that highlights the historical and local specificity that has to be accounted for in complete understanding and effective manipulation of ecological systems.

Problems in restoration

Modern ecological principles show the shortcomings of some cases of restoration practice. Restoration practice is often based on the assumption that nature is fixed and unchanging (Jordan 1993). In the United States, several national parks have been treated that way. Examples include Yellowstone, the Grand Tetons, Yosemite and Everglades National Parks (Cronon 1995). These are places we wish to preserve forever, and which in general are perceived by most people as climax communities that are ever persistent. What happens when these systems experience a relatively infrequent but rather dramatic event from the public perspective? Extensive fires in Yellowstone National Park in 1988 resulted in a public outcry and review of management policies. This public response indicates how poorly people understand the dynamics of natural systems and instead tend to objectify and idealize nature. An idealized view of nature, however, makes it more difficult to understand that natural communities are constantly changing and that a number of internal and external processes maintain these systems. If natural and dynamic systems are viewed as in some ideal state, systems are presumed to have a single range of characteristics that can be preserved. This assumption might be applied to various system attributes, like biogeochemical dynamics, productivity, or composition. But such an assumption of objectification and idealization may thwart successful restoration.

An additional problem with the assumption that nature is fixed or in balance is the adoption of simplistic goals for restoration. What should be our goals when we begin the restoration of a natural system? Our experience is that many projects begin with vague goals such as returning the system to some primeval state in which it can take care of itself. This common view of ecological systems de-emphasizes the role of dynamic and multidimensional processes that have created these systems, and lacks the understanding of the human and landscape contexts in which processes and ecosystems occur. Modern ecology offers an alternative approach.

We begin an overview of these ideas by noting that an inclusive ecosystem concept should be used, and that it has implications that can help avoid taking static and ideal views of nature as the motivation of restoration practice. We then summarize the contemporary paradigm, detail the nature of ecological contingency as a feature of the natural world that influences restoration, and move to examples of the application of these principles in the natural world. More crucial in restoration is the problem of balancing the need to work with idiosyncratic sites, and, in the absence of detailed information on all sites, the need to use the general principles of ecology. This last theme appears throughout much of the chapter in specific principles and examples.

The ecosystem concept

The inclusive ecosystem concept is an excellent starting place for relating modern ecology to restoration practice. It can serve as a cornerstone for a theory of ecological restoration that is realistic, clear, and complete. Tansley (1935) articulated the first clear definition of the ecosystem that continues to be used and reinforced (Likens 1992). Although there have been interpretations that see the ecosystem as only a series of black boxes connected by the flow of energy and matter (reviewed by Golley 1993), the ecosystem is considered to be a collection of interacting organisms along with the physical environment, including matter and energy that they may assimilate, in some specified location. This definition of the ecosystem invites ecologists to understand the fluxes of energy, matter, and information, but it also invites understanding of the evolution of system components, the historical trajectory of the system, the interaction of assemblages of organisms, the behaviour and persistence of populations, and the fluxes of information embodied in the genetic and other structures of the ecosystem.

The inclusiveness of the definition of the ecosystem suggests an inclusive perspective on the discipline of ecology as a whole. Classical definitions of ecology emphasized the organism (e.g., Haeckel 1866), and early restoration, conservation, and management approaches similarly focused on one or several species. However, taking the inclusive nature of the ecosystem seriously, and accounting for the rich variety of phenomena ecologists routinely examine, suggests the need for a broader definition of the field: 'Ecology is the scientific study of the processes influencing the distribution and abundance of organisms, the interactions among organisms, and the interactions between organisms and the transformation and flux of energy and matter' (Likens 1992). Each of the subdisciplines of ecology emphasizes different aspects of this broad suite of interactions and influences. For restoration, the broad definition suggests that the goals and tools of restoration must also be broad indeed. And, given whatever the target chosen, it surely is embedded in the network of interactions. The implications can be emphasized by considering three aspects of the term 'ecosystem'. These aspects are the basic meaning, the models used to put the meaning into practice, and the metaphorical breadth of the term. We explain these aspects below.

The basic definition of the ecosystem is the fundamental meaning that ecologists and practitioners must use. We have already provided the essence of the definition. Here we recall two aspects of the definition. First, common to all instances of ecosystem is the need to specify a spatial location and extent. Secondly, the ecosystem involves biotic structure, physical environment and setting, and the exchanges within and among these two. But in order to use such an abstract definition, the meaning must be operationalized in an explicit model. Models can show the components of a system, the interactions among them, and the controls on the interactions.

In the case of ecosystems, the interactions can include transfers of energy, matter, and information, impact on biotic structure and composition through competitive, feeding, and mutualistic interactions among organisms, and other sorts of interactions. Because of the number of interactions and structures that can be found within a single ecosystem, ecologists and those who work with real ecosystems must specify the model they base their studies, conclusions, and applications upon. Failing to specify a model that can be communicated to the various parties involved in restoration may lead to confusion and disappointment.

The final way to use the ecosystem concept is as a metaphor. The image is much less exact than a model, but it is likely to be broader than any particular model. Such breadth may allow people to detect key features of real ecosystems that have been left out of the model used to motivate, plan, and assess a restoration. Because ecosystems have a necessary spatial extent, the metaphor, in combination with the insights of the modern paradigm, alerts ecologists to look beyond the boundary they have had to set, to determine whether important influences appear from outside the boundaries, or outside the spatial extent assumed by the model. Thus the metaphor invites consideration of the context of the focal ecosystem to be understood or restored, issues which are generally the focus of landscape ecology. The metaphor also reminds us of the temporal dimension of ecosystems. Because transformation, interactions, and fluxes are part of the basic definition of the ecosystem, and because each of these phenomena must be expressed as a rate, a time dimension is a necessary part of an ecosystem.

The consideration of the ecosystem as meaning and metaphor brings us to an understanding of one of the key elements in the title of this chapter: ecosystem process. We detail that understanding below.

Ecosystem processes and the contemporary ecological paradigm

Ecosystem theories emphasize the flux of energy and materials and are inclusive of processes as disparate as nitrogen flow and community dynamics. Recently, ecosystem definitions more inclusive of interactions among ecological entities have been proposed (Likens 1992; Jones & Lawton 1995). Ecosystem theories, however, have developed from two distinct sets of assumptions. Classically, ecosystems are thought to reach stable successional endpoints, after which processes are in dynamic equilibrium. This model of ecosystems suggests that systems are closed and self-regulating, that, during succession, ecosystems will increasingly control the flow of minerals and energy. Consequently, such models of ecosystems are seen as deterministic, and processes or events that move the ecosystem away from this equilibrium are considered disturbances. Disturbances are thought, under the classical view, to be exceptional.

In contrast, the contemporary paradigm assumes that ecosystems are open, can be regulated by external processes, and are subject to natural disturbances. They may have multiple and probabilistic successions, which at some scales may lead to multiple equilibria, while at other scales may fail to reach an equilibrium. Because systems are open to external regulation, humans and their effects must be incorporated in ecological models for restoration ecology to be effective. Thus, rather than viewing ecosystems as being 'in balance', systems are seen as in flux from some scale or perspective (Pickett *et al.* 1992). Ecological theory has shifted to this contemporary view because of both empirical explorations of natural systems (e.g., Wiens 1986) as well as the prominent failure of management based on older equilibrial assumptions (Botkin 1990).

Implicit in the contemporary approach to ecosystem dynamics is a requirement to understand process and context. Processes refer to system dynamics and the mechanisms underlying them, while context refers to the spatial influences on a system. First we consider processes. Because stable endpoints only play a small role, if any, in system structure, attention must move to ongoing processes. Processes contribute to variation. Events like disturbances can affect systems because systems are open. Dynamics of ecosystems can be seen at a variety of scales as exemplified by the movement of, and interactions among, individual organisms, the transformation of energy and materials, successional trajectories, patch dynamics, and responses to 'large' (regional–global) scale environmental change. If restoration is focused on re-establishing functioning and self-sustaining systems, then recapturing the dynamics of systems may be dependent on ensuring that appropriate processes are returned (e.g., Niering & Warren 1980; Niering 1987; Race 1985; D'Avenzo 1990). This requires understanding of the degree to which external processes or events in the past were important in the dynamics of the system, and whether they can continue in the restored site.

Processes refer to biotic or abiotic interactions that influence dynamics. Any process may influence a number of ecosystem characteristics simultaneously. A clear example of this is the differential effect of a fire, killing some individuals or species while stimulating the germination of others. Fires also transform nutrient dynamics by mineralizing nutrients previously bound up in organic matter. Furthermore, fires alter substantially local microclimates by the loss of cover and the presence of dark ash over the soil surface. All these changes together increase the rate and nature of vegetation dynamics, triggering succession. The fact that processes affect the dynamics of a variety of ecosystem aspects simultaneously illustrates the need to approach restoration from a variety of perspectives rather than relying on composition or some other characteristic alone to evaluate restoration success. The example of fire expands our attention from process to include spatial context.

Context specifically refers to the spatial connections of the site of interest with landscape around it. For example, differences in continuity of vegetation strongly influence the movement and propagation of a number of processes such as fire or pathogens. Fire is also a good example of a process which often starts outside a particular site and depends upon the relative continuity of vegetation to permit its flow from site to site. The context of the site is critical to whether historical fire regimes continue. Similarly, the rain of propagules into a site depends greatly on the types of vegetation nearby and how disturbed they are. The heterogeneity of adjacent landscapes impacts the flux of water and nutrients of sites downslope. All these examples emphasize the importance of the interactions of a site with its surroundings. Ecosystems are open to processes that arise externally to them at any scale considered, whether global atmospheric changes or the immigration of fungal spores. The spatial extent that needs to be included in the context depends on a number of considerations, such as the scale of the process of interest and how other features of the landscape may influence processes (Naveh & Lieberman 1984; Forman & Godron 1986; Turner 1989).

Humans have a significant influence on a number of processes and have modified much of the landscape. Human impacts can be an overwhelming influence on site restoration through disturbances and through processes arising in adjacent habitats modifying historical patterns. When houses dominate areas next to wildland reserves, humans tend to increase the frequency or magnitude of some processes while reducing others. For example, in central California, urban – wildland boundaries force managers to suppress wildfire in vegetation dependent on fire for its maintenance. At the same time, urban areas become sources of invasive species, of trails and roads into the managed site, and of other impacts. Restoring or managing vegetation in such a human-modified context requires active and ongoing intervention to maintain natural vegetation influenced by the frequency and composition of processes arising outside of the site. Systems cannot be 'self-sustaining' from the idealized perspective because contextual processes have been modified.

These concepts of contemporary ecology lead to a simple model of ecosystem dynamics. In this model, ecosystem characteristics and dynamics are dependent on two general sets of processes, those that are contained within the site and those external processes that influence the system. Both kinds of processes maintain the structure and the functioning of the ecosystem. While we have referred to the external set of processes as context, we emphasize that processes represent continua of extent, of origin, of magnitude, and of other characteristics; therefore, for any subset of processes, whether nitrogen cycling or species recruitment, reference to both internal and contextual influences is necessary. Ecosystems are in continuous flux for all characteristics at some scale. We emphasize that such a dynamic model is critical for successful restoration ecology, because it is the restoration or maintenance of the responsible processes underlying structure and function that will meet long-term restoration objectives.

The remainder of this chapter explores the nature of the spatial and temporal dynamics of ecosystems as a foundation for restoration. The nature of these dynamics and spatial contexts suggest that restoration ecology must use models that treat ecological systems as constantly dynamic and open to outside processes. Recognizing process and context indicates the inherent contingency of natural systems. Such contingency requires that two concepts must underlie that development of restoration models and approaches. One is that restoration must be seen as part of an ongoing process, not as a discrete event. A second concept is that historical uniqueness means no ideal reference states exist for systems, instead, more than one reference state must be considered to develop criteria for restoration projects; the diversity of potential reference conditions should be analysed from the context of the site being managed.

Examples of process and context in light of the contemporary paradigm

When we consider process and context together, as well as their temporal patterns, we are forced to conclude that any particular site results from the historically unique combination of processes for that location, which we refer to as contingency. In extensive landscapes of natural vegetation, unique features may not seem significant due to the influence of larger-scale processes that unify the structure and dynamics of the landscape. Fragmentation of areas by human management and the growth of human populations, however, has significantly shifted the importance of processes. Remaining historical natural processes are restricted to either smaller scales that are contained within sites, or to larger-scale processes like atmospheric or meteorological characteristics not directly influenced by fragmentation. Although the interactions among species or the interaction of species with their physical environment can be generalized, the specific dynamics of any system and the trajectories it may take after initiating restoration practices all depend on its prior history, accidental arrival or extinction of species, current processes acting on the site, and the site's place in the landscape.

Different plant communities may exhibit stable points in composition. Ecosystems that are species poor or that are strongly governed by a limited array of processes may well result in repeatable stable states in a variety of locations. Other systems, however, even relatively species poor systems, may offer a range of ecologically valid reference states. Ecologists who have reconstructed the history or palaeohistory of particular vegetation types are often struck by the differences between current and past composition. But to provide objectives for restoration projects, it is critical to decide on reference conditions. We can use the history as well as the current diversity of conditions to determine a set of possible reference states. What is important is that there is no one ideal reference state for any type of community or ecosystem. Instead, the context and history of the site being restored should be used to determine valid reference states.

Restoration of a site is driven by a number of societal as well as ecological goals; explicit identification of those objectives, as we have emphasized before (Pickett *et al.* 1992, Parker 1993; Pickett & Parker 1994; Pickett & Ostfeld 1994), is fundamental for the establishment of restoration ecology as a science. For an array of different sites to be restored, restricting restoration objectives to a single ideal reference state can create fundamental problems because the environmental context may differ among the sites (Pickett & Parker 1994). While no single ideal reference state exists, some argue that reference states can be chosen arbitrarily under certain circumstances (e.g., Aronson, Dhillion, & Le Floc'h 1994). We strongly disagree with the use of 'arbitrary' reference states (Aronson *et al.* 1994); instead, a reference system should be based upon the range of what is possible, illustrated by spatial and temporal variation in natural systems, and on contextual issues of how influential processes have been modified. Without focusing on the condition of a site and the external processes acting on the site, restoration can only pretend to create self-sustainability in most circumstances. Because any 'ecosystem of reference' is simply a manifestation of the goals and objectives of the restoration, we find it important to re-emphasize that it is by managing processes that the structure and function of an ecosystem is restored.

We can illustrate our concerns about process and context with an example of variation within vegetation types provided by coastal scrub vegetation in California. This is a shrub-dominated system restricted to near-coastal locations from northern California into Baja California. The vegetation is found on a diversity of soil types, exposures, and climatic conditions, and contains a large number of species. As a consequence, there is great variation in the compositional expression of this ecosystem type and there have been a number of attempts to classify sites within the broad vegetation types (e.g., Westman 1983). Clearly, such broad regional shifts in composition would restrict reference states to something relatively local, but local variation can also be great. High species diversity is expressed among sites and this diversity is sensitive to shifts in topography, distance from the ocean, and soil type. Sites within a few kilometres of each other can share less than half the total species in common when comparing north-facing communities on clay with south-facing communities on granite or any exposure on sand-dunes. Sites may express a range of topography, soil, or contextual processes that make each location distinct in consideration from the others. Each of these conditions alone requires a variety of reference states. Yet the vegetation reflects all of those conditions. Hence, the variety of possible reference states is huge.

A number of highly disturbed sites in the region of San Francisco, California, are currently receiving restoration efforts or are to be restored in the near future. Two specific restoration sites within this area illustrate our meaning of context. One example lies along a ridgeline surrounded by high-density urban development, and contains a large proportion of invasive species. Even with restoration, propagules of the invasives will continue to rain onto the site and represent an ongoing contextual process. People from the surrounding neighbourhoods will visit the site providing continuous fine disturbances. The second example is located only a few kilometres away on a large point of land surrounded by the Pacific Ocean on three sides. At this second location, coastal scrub had been disturbed by the presence of an off-road vehicle club for the last several decades before the purchase of the site for preservation. This ocean site is relatively isolated, and for most of the perimeter is in contact with natural coastal vegetation.

Two aspects of these examples are relevant to the choice of reference states. One is that, even though close in proximity to one another, the plant communities of the two sites are substantially different. The reasons for this difference lies in environmental differences between ridgeline and ocean edge sites, like soil type, exposure to wind and summer fog, historical isolation, and a number of other factors. Within the two restoration sites, substantial variation in composition and structure results from the same processes influenced by topography, soils, and exposures. There is no ideal reference state for this vegetation throughout the region or for these two sites. Adding other restoration sites within coastal scrub to this example only increases the emphasis on how, with variation in soil, slope, exposure, and other conditions, all sites and areas within sites should have different reference conditions for composition and processes.

These two sites also illustrate how context can influence our understanding of what restoration actually is. For the ocean site, restoration might be a relatively easy process in which soils are reconstructed and new plants established. Because a matrix of natural vegetation exists, and because the surrounding areas are mostly natural, a functioning, self-sustaining natural system may result from this restoration 'event'. Unfortunately, this may be an exception to more typical restoration sites. The ridgeline site surrounded by urban housing may seem more appropriate as a restoration example. Here contextual processes have been modified completely by humans, and restoration should be viewed as an ongoing intervention. As a general approach, we feel restoration is more appropriately considered a process, with the degree of active intervention being determined by contextual circumstances (Figure 3.1). In this sense, distinctions between restoration ecology and management of natural vegetation begin to break down.

Conclusions: enhancing restoration ecology

Contemporary approaches in ecology have established that, at most scales of investigation or levels of organization, ecological systems are not deterministic in characteristics like composition, successional pathways, mineral flow, energy flow, or productivity. As a consequence, the variation in ecosystems is simply the reflection of a history of species invasions responding to biotic interactions and the continuous influence of a number of abiotic processes. Crucially, our view of ecosystems recognizes that processes arising outside the system can regulate the system as much as can internal processes (Turner 1989). Together, these concepts lead to an inclusive model of ecosystems as open and variable in successional pathways and stable points, fluctuating in energy and mineral flow, and, especially from a restoration or conservation perspective, to a model that must include the role and impact of humans.

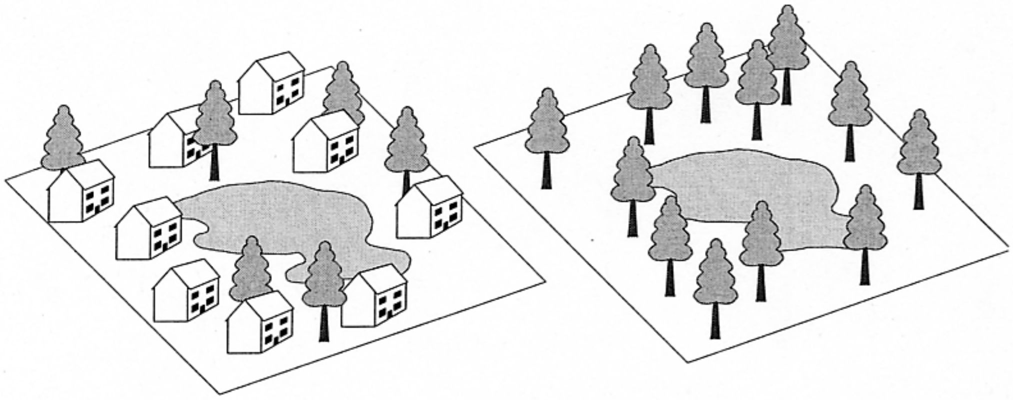

Figure 3.1. The context of restoration sites can strongly influence the processes that influence site dynamics. The two sites illustrated above show a site in a context of high-density housing, in the first case, while, in the second, the site is surrounded by natural vegetation. In the first case, many natural processes will have been suppressed, while other processes, like the dispersal of invasive species, are enhanced. Restoration of this first site will require continuous intervention. Restoration of the second site places it into continuity with ongoing natural processes that enhance restoration rates. The scale at which processes can impact sites suggests that the landscape context can be overwhelmingly important in assessing restoration.

Human impact varies in its rate and magnitude, but in almost all cases has increased the rate of change within ecosystems. Understanding the role of both internal and external processes is critical for developing restoration models. The natural world has hard-and-fast limits in its ability to respond to human-generated pressures. The basic physiological limits, historical availability of suitable species, and the rates of evolution all constrain the ability of nature to adapt successfully or to accommodate change (Pickett & Ostfeld 1994). The new paradigm suggests that the more we understand about these limits, the better we can predict or evaluate the effect of a human-caused change, and successfully intervene in our management.

Historically many cultures have tended to either idealize or anthropomorphize 'nature'. The use of the word 'nature' in the United States tends to evoke an image of an entity 'out there', separate and distinct from human communities (Cronon 1995). This objectification of natural ecosystems has contributed to the metaphor of ecological systems as balanced in processes and capable of maintaining themselves in a climax condition. Too often conservation of a system means saving it 'as it is', imposing a concept of stability onto dynamic systems. For restoration ecology, this metaphor would suggest that such deterministic systems would only require a single restoration event to initiate a self-regulating process returning to an ideal reference state or climax. These perspectives deny the complex dimensionality and dynamic condition of ecological systems.

Ecologists tend to celebrate the distinction of new approaches to the science by the erection of disciplines. New societies and journals soon follow and these are often useful for specialists working out concepts and principles unique to, or focused on, that discipline. In the context of separating themselves from the objectives of traditional applied ecology, scientists concerned with the restoration, conservation, and management of natural systems have laid claim to their place as new disciplines. We agree with this process for the development and maturation of models and applications based on these practical goals and new perspectives. Even now, in the early states of the history of these disciplines, it seems appropriate to point out some of the ways in which they are beginning to converge. The underlying basis for this convergence is based on two points, that basic ecological models unify these disciplines on the one hand, and that contingency limits the usefulness of applying general models indiscriminately.

Previously, differences in the scale of the ecosystem or the level of interest distinguished the disciplines of conservation, management, and restoration. For example, a focus on rare animals and plants dominated conservation biology early on, while restoration was focused on the initial states of assembling ecosystems in highly disturbed locations such as former mine sites or newly created sites for wetlands. However, it has become clear that species cannot be preserved without their genetic and ecological contexts, and that sites cannot be restored without considering their historical and current ecological contexts.

We feel the contemporary paradigm emphasizes this convergence among ecological applications. Systems are dynamic and are maintained by a continuous environmental regime of processes. Furthermore, because ecosystems are open to regulation from external processes as well as from internal processes, the environmental regime of any site receiving restoration efforts includes the context of that site. When contextual processes begin to dominate a local restored site and shift the trajectory of site dynamics away from restoration objectives, more or modified intervention is required. At this stage, restoration objectives, conservation objectives, and management objectives begin to converge completely.

If this congruence of disciplines and approaches is true, then what are the unique aspects of restoration ecology that provide it with the status of a distinct discipline? Our conclusion is that, because restoration is concerned with tangible locations, restoration ecology must balance the use of general models of ecological systems with the unique problems provided by the context of each particular location. If we use the analogy of restoration as managing succession, then the problem for restoration is that most ecological models are articulated at higher, more general levels of hierarchical frameworks of processes (Pickett, Collins, & Armesto 1987), while restoration ecologists must somehow determine the differential impacts of local circumstances, processes found at the lowest level of the conceptual hierarchical framework (Luken 1990).

We conclude by emphasizing the need for restoration ecology to develop models that combine general principles with unique site conditions. The detailed points of the contemporary paradigm point out the ways ecologists have come to understand the linkages, processes, opportunities, and constraints that shape the various components of biodiversity. Systems are open to important controlling factors, often externally regulated, frequently probabilistic in their dynamics, subject to natural disturbances and episodic events, not necessarily in short-term or fine-scale equilibrium, and contain humans. In this context, an ecosystem's structure and dynamics are maintained by a particular and historical environmental regime of biotic and abiotic processes. This model, based on contemporary views of ecosystem dynamics (e.g., Pickett *et al.* 1987; Pickett & McDonnell 1989; Wu & Loucks 1995; Brand & Parker 1995; Parker & Pickett 1997), incorporates the essential aspects we have argued for in this chapter. The challenge for restoration ecology is to abandon the 'balance of nature' for a balance of approaches incorporating the general with the specific.

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