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Towards a Science of Ecological Management

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Ecosystems are dynamic assemblages of interacting components, self−organized into evanescent patterns of interaction on multiple scales of space and time (Levin 1992). The essential constant is change: the balance of Nature describes a system far from equilibrium, alternating between periods of relative stasis and dramatic change.

The pervasiveness of this perspective is evident in the fact that it emerges anew from multiple theories, each built on different foundations of evidence. Darwin certainly recognized the importance of change, and its essential role in the emergence of biological diversity. More recently, theories of punctuated equilibrium have built on the creative potential of periods of major change following stasis (Gould and Eldredge 1977). In ecological systems, Watt (1947) and MacArthur and Wilson (1967) emphasized the nonequilibrium nature of local population dynamics, a phenomenon of fundamental importance for the organization of communities and the maintenance of biodiversity (Levin and Paine 1974, Pickett and White 1985, Gilpin and Hanski 1991). More recently, Holling (1995) has expanded these notions, arguing that ecosystems go through regular cycles of organization and collapse.

Holling argues that aggrading ecosystems will be characterized by patterns of growth and exploitation, and by increasing connectedness among their elements. Through time, *r*−selected species will be replaced by *K*−selected species (in a phase Holling calls conservation), leading ultimately to overconnectedness, release of stored nutrients, reorganization, and potential flip into alternative domains of behavior. The words are different, but the conceptualization bears remarkable similarity to Bak's (1996:1588) discussion of self−organized criticality as a generic feature of self−organizing systems. Bak's sandpile model, reformulated in the language of ecosystem ontogeny, would argue that, through time, a developing ecosystem will become more and more connected, increasing the degree of correlation among its dynamical parts. In that connectedness are the seeds of major change, the release and reorganization described by Holling.

One may argue about the universality of any of these perspectives and the degree to which evolutionary forces might modify them; but it has become well accepted among ecologists that classical equilibrium theories are woefully inadequate. Slowly, perhaps too slowly, this acceptance has begun to affect the management of natural resources −− for example, in the recognition of the ecological role of fire in renewing limiting resources, or in the advent of metapopulation models in conservation science.

Carpenter, Brock, and Hansen (1999, this issue) explicitly recognize the dynamic and nonlinear nature of ecosystems, and the fact that they self−organize from the local interactions among their components. That is, ecosystems are complex, adaptive systems (Levin 1998) and, hence, are characterized by historical dependency, complex dynamics, and multiple basins of attraction. The management of such systems presents fundamental challenges, made especially difficult by the fact that the putative controllers (humans) are essential parts of the system and, hence, essential parts of the problem. Following Holling and Meffe (1996), Carpenter et al. (1999) reject command−and−control approaches as being worse than inadequate, arguing for the need to build flexible, adaptive institutions, and recognizing the essential hegemony of individual decisions as cornerstones of effective management plans.

The science of management of large systems is less than exact, and simulation models provide a powerful way for informing decision makers. Just as a pilot gains understanding of the consequences of his or her decisions by hours spent on flight simulators, so too can ecosystem and resource managers gain insights through exploration of simulation games that mimic the challenges they face. Buzz Holling, Carl Walters, and Ray Hilborn, with numerous collaborators, pioneered such methodology in their adaptive management workshops at the University of British Columbia two decades ago, and Carpenter et al. (1999, this issue) build on that approach. Their system of choice involves lake eutrophication through nonpoint pollution, but other systems would serve as well. They explore a number of different management structures and elucidate the different sorts of behaviors possible. The downloadable software that accompanies the paper takes publication into a new domain, allowing imitation of the UBC workshops. The potential for this powerful combination of ordinary and extraordinary fare is just the sort of advance that sets *Conservation Ecology* apart from standard journals.

There are a number of lessons that emerge from this study and guide it. Most important is the importance of experimentation, learning, and adaptation (Holling 1978, Lee 1993, Janssen and Carpenter 1999). Furthermore, just as management must be adaptive, one must recognize the powerful adaptive and self−organizing forces that shape ecosystems (Levin 1998:1417). Top−down approaches cannot adequately account for these irresistible forces; on the other hand, flexible and adaptive approaches can potentially harness them for the greater good.

More generally, recognition of the complex, adaptive nature of ecosystems and the biosphere provides guidelines for sound management that are ignored at our peril, but are addressed in approaches such as that of Carpenter et al. (1999). Elsewhere, in *Fragile Dominion* (Levin 1999), I summarize these in Eight Commandments of Environmental Management:

1. Reduce uncertainty
2. Expect surprise
3. Maintain heterogeneity
4. Sustain modularity
5. Preserve redundancy
6. Tighten feedback loops
7. Build trust
8. Do unto others as you would have them do unto you

Classical command and control approaches rarely can incorporate all of these principles, because optimization according to multiple sets of criteria can present irresolvable conflicts. Exploratory and adaptive approaches, such as those explored by Carpenter et al. (this issue), provide hope for harmonizing management with the natural forces, and for maintaining ecosystems and the services they provide.

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