Chapter 23
The Flux of Nature: Changing Worldviews and Inclusive Concepts

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Abstract The interaction of ecology and the study and application of environmental ethics can be facilitated by understanding the status of the fundamental background assumptions of the science. The classical paradigm of ecology, now superseded, focused on organisms and framed the science in a primarily equilibrium perspective. Steady state, homeostasis, and stability were hallmarks of ecological systems under this worldview. With the benefit of hindsight, the specific assumptions of the equilibrium paradigm are seen to be that (1) ecological systems are materially closed; (2) they are self-regulating; (3) an equilibrium state exists for each system; (4) disturbance is rare or negligible; (5) recovery from any disturbance that does occur is deterministic, and leads to the expected equilibrium state; and (6) humans are external to ecological systems and are a negative force. As the organismal viewpoint gave way to more inclusive theories, such as the ecosystem and landscape ecology, and data sets extended for longer periods of time, it became clear that the equilibrium assumptions did not always hold. The shift in worldview occasioned by new data as well as by conceptual flexibility, can be summarized by a new inclusive or non-equilibrium paradigm. It accepts (1) the material openness of ecological systems; (2) the role of external regulation; (3) the absence or transience of equilibrium states; (4) the commonness and significance of natural and human-caused disturbances; (5) the multiple pathways of system dynamics, and (6) the pervasive involvement of human actors, both local and distant, in ecosystems. Ecological concepts engage technical definitions, technical models, and metaphorical implications that are relevant to their connections with ethics.

Keywords Ecosystem • History • Metaphor • Paradigm • Social-ecological system

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23.1 Introduction

Considering worldviews exposes several complexities within the science of ecology. Because worldviews can shape the relationship of science and ethics, at its best, exploring the complexity of ecological paradigms may smooth the way for linking ecology and ethics. At least, such exploration can mark the sharp curves and rough spots in the road. Therefore the major goal of this chapter is to expose key aspects of the paradigms in ecological science. This complexity is expressed across the topic areas that the discipline covers, and across time, reflecting the changes that ecological paradigms have undergone.

23.2 Ecology's Initial Paradigm

The science of ecology grew out of the great eighteenth and nineteenth century flowering of biology. Ecology merges important threads from taxonomy, biogeography, physiology, anatomy, and evolution. These root sciences inform us about the diversity, distribution, internal functioning, internal structure, and change in organisms. Ecology as the inheritor of the riches of these older research traditions clearly is centered on organisms. However, it took the concerns of these other disciplines outside of the laboratory, and was originally considered by some to be field physiology. Broader definitions dubbed it the science of the relationships between organisms and environment. The organisms were the system and the air, water, materials, and physical conditions were then the environment.

The first ecological theories were shaped by two sciences in particular; one was biological and the other was not. Ecology was launched in the shadow of the master science of the nineteenth century, Newtonian physics, from which it learned determinism, direct causality, and ahistorical explanation. In addition, the progress-oriented interpretations of Darwinian evolution served as a model of ecological dynamics. This second fact may seem odd, given that natural selection, the principal mechanism of Darwinian evolution, says nothing about progress or "direction" of change.

The first paradigm of ecology therefore focused on organisms – mainly plants and animals – and sought explanation of change and regulation within conspecific populations or co-occurring assemblages of different species. Competition and predation were the predominant mechanisms proposed, and research into limiting factors and adaptation of species to physical conditions were important frontiers. The environment, the complex of physical and chemical factors and conditions external to organisms, was most often taken as a fixed background. Change in assemblages was directional and progressive, and led to stable collections of species. Emphasis was on the equilibrium conditions that emerged from organism interaction, and disturbance and disturbed sites were neglected as research topics (Simberloff 1980). Behind all these assumptions about organisms and their interactions, lurked another assumption – that the organisms of interest did not include humans (McDonnell and

Table 23.1 Background assumptions of the equilibrium paradigm

1	Ecological systems are materially closed.
2	Ecological systems are self-regulating.
3	An equilibrium state exists for each system.
4	Disturbance is rare or negligible.
5	Recovery from any disturbance is deterministic and returns to the equilibrium state.
6	Humans are external to ecosystems, and are a negative force.

Pickett 1993). This last was in spite of attempts by some researchers to include humans among the research topics in the earliest issues of America's then new journal, *Ecology*. The founding assumptions seem clear to us after decades of hindsight as components of a worldview, or a paradigm (Table 23.1).

This worldview, labeled the "equilibrium paradigm" (Pickett et al. 1992), flavored many generations of textbooks, and was associated with the dominant streams of ecological research (Botkin 1990).

23.3 Emergence of the Ecosystem

If ecology's first emphasis was on organisms and their interactions, it's next emphasis highlighted the feedbacks between organisms and environment. An early version of this was the *reaction* of the environment to the presence and activities of plants through the process of succession. Frederic Clements, the predominant theorist of vegetation change in ecology's pioneering decades, noted that an environment occupied by plants undergoes change as a result of the structures and activities of those plants (Clements 1916). As a consequence, the environment itself changes, and different plants are then favored. Hence, a feedback between plants and environment was a core process in his theory of succession. Clements' focus on the feedback was shaped by his attention to the adaptation of organisms to their environment. He used the metaphor of the community as an organism to symbolize the tightness and power of the feedback.

Many ecologists found Clements' use of the organismal metaphor harmfully inexact and problematical. Therefore, Arthur Tansley, perhaps the premier British plant ecologist of his day, mounted a critique of Clements' framing (Tansley 1935). As an antidote to the Clementsian metaphor, Tansley proposed the ecosystem concept in 1935. He claimed to use the concept of *system* in precisely the way it was used in physics, as a entity comprising other interacting entities. This concept allows analysis of components and interactions in the context of the larger collection, but also allows the properties and functioning of the more inclusive entity to be understood and characterized. The system concept provides more scientific utility than the organismal metaphor, which explains by analogy rather than mechanism.

Table 23.2 Background assumptions of the contemporary, non-equilibrium paradigm

1	Ecological systems are materially, energetically, and informationally open.
2	Regulating processes and events may arise outside of a focal ecological system.
3	There are many states a system can take, and there may be no single equilibrium.
4	Disturbance is a recurrent feature of natural systems.
5	Response to disturbance may be non-linear and exhibit multiple pathways and persistent states.
6	Humans and their effects are part of virtually any ecosystem on Earth.

Tansley's stroke of brilliance was to indicate that organisms and environment were in fact part of a single system. Recall that when ecology is seen as the study of organisms and interaction, that the organisms are the system, and the physical and chemical conditions are the surrounding environment. Tansley flipped the perspective, and indicated that the organisms were also part of a larger system. He defined this more inclusive, organism-based system as the ecosystem. Such systems would have to include what had previously been the external conditions – called the environment when the focus was on organisms as systems themselves. This step introduces the potential for confusion about the term "environment," however. The confusion is dealt with by specifying the model of the system of interest: what are the components, what are the interactions, what is the spatial boundary, what is the temporal scale? This approach is powerful enough in its generality and precise enough in its specification not to need the organismal metaphor to move it forward in research.

The ecosystem concept took several more decades to mature into a focus for research and a tool for application in mainstream ecology (Golley 1993; Hagen 1992). It eventually supported coarse scale budgetary approaches, in which inputs and outputs of large systems were documented, and in which the internal flows among living and non-living components were traced (Odum 1971). It compared systems of different ages and different positions on gradients of stress (Bormann and Likens 1979; Likens 1992). It ultimately began to focus on the roles of species, including composition and richness (Jones and Lawton 1995), and the effect of spatial heterogeneity within ecosystems on their structure, functioning, and change (Lovett et al. 2005). In addition, material and non-solar energy subsidies from outside a spatially delimited ecosystem were discovered to be common and important. As ecosystem ecology developed, a "process approach" took hold that broke budgets down into their component fluxes, pathways, and controls. Furthermore, ecologists came to study and understand systems that were far from compositional or biogeochemical equilibrium. Finally, ecologists came to recognize that people, their activates, and their structural legacies were often cryptic components of the ecosystems they had been studying as if pristine (McDonnell and Pickett 1993). The changes in focus and content during the maturation of ecosystem science helps complete the emergence of the contemporary paradigm in ecology (Table 23.2).

Is it a coincidence that Aldo Leopold (Leopold 1949) was struggling with how to conceptualize and recognize larger systems beyond individual organisms at roughly the same time that the ecosystem idea was being proposed and first put into play in research? His idea of a community of the land seems to have some of the same features as the ecosystem concept. It encompasses all the organisms – including humans – in a specified area of landscape. Although Leopold's poetry is hard to beat, it seems that his thinking has clear parallels to the emerging science of ecosystem ecology. He might have found the ecosystem concept useful had it been available and widely accepted. That was not to happen until the 1950s and 1960s.

23.4 Emergence of Inclusive Paradigms of Ecology

The individual-based approach of organismal ecology and the material-centered approach of ecosystem ecology are the bookends one of the major contrasts within the science of ecology (Pickett et al. 2007). Although research has increasingly exploited some combination of these approaches, much empirical work and conceptualization lies toward the extremes. The informal tag for this contrast is a conceptual axis of "things versus stuff."

A second contrast in ecology is the focus on contemporary, instantaneous relationships compared to a focus on history and echoes of the past as controls of current system structure and process. Contemporary or instantaneous causation was favored by the classical physics model of "good science." However, as ecologists accumulated increasingly long-term data on existing systems, or were able to extend their understanding by using paleoecological or historical records, the role of past system states became clearer. This methodological axis contrasts "then versus now" as the second paradigm within ecology. Together, the things-stuff and then-now axes define an ideal for integration in ecology (Fig. 23.1). The most comprehensive explanations and models will consider organismal and other structural entities – things – and the fluxes of materials, energy, and information – stuff. Comprehensive models or suites of models will also consider contemporary causal links, legacies of past interactions, and gradually emerging indirect effects – that is, both "then and now" (Cadenasso et al. 2006).

A third dimension of conceptualization in ecology is relevant to both these internal paradigms. In the early days of the discipline, researchers introduced the radical idea that ecological systems were not static. The theory of succession, introduced to codify, exploit, and test the implications of this assumption, was progress-oriented and deterministic, and proposed simple pathways of change. However, two things challenged this worldview. One, as ecology got older, so the data sets on system dynamics got longer (Weatherhead 1986). This accumulated knowledge showed multiple pathways of succession (Johnson and Miyanishi 2008), the common failure of an expected "climax" composition to emerge, and the pervasive role of natural disturbances (Botkin 1990; Pickett et al. 1992).

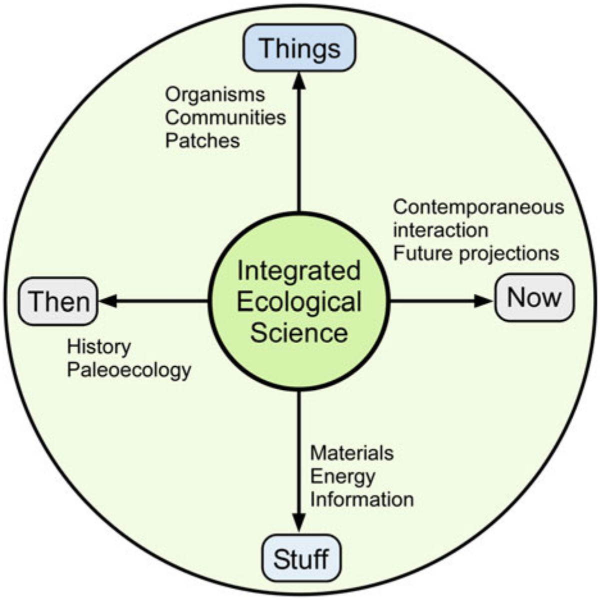

Fig. 23.1 The two axes of contrast in ecological science (Based on Pickett et al. 2007)

23.4.1 The Inclusive Ecosystem

The conceptual axes outlined so far suggest a space in which the ecosystem concept can be put to work. Combining that with the six points of the contemporary paradigm (Table 23.2) in fact suggests a more inclusive set of connotations for the ecosystem concept.

First, the ecosystem concept refers to any spatial scale. Some ecosystems can be walked into, some can be walked across in a day, and others can be trampled underfoot. As long as all the organisms, their interactions, and a boundary are specified, the concept is appropriate (Pickett and Cadenasso 2002).

Second, although the holological and biogeochemical approaches have characterized ecosystem ecology, focusing on organisms and diversity within ecosystems is productive. The identity of species in biogeochemical processes and the role of species diversity with its issues of redundancy and replacement are also appropriate concerns for ecosystem ecology (Jones and Lawton 1995).

Third, spatial heterogeneity is important for ecosystem structure and processes (Lovett et al. 2005). Internal heterogeneity may set up "hotspots" of transformation of energy and matter. Heterogeneity may affect the existence or location of sources and sinks for materials in ecosystems. Such heterogeneity may originate as part of a relatively permanent topographic template, or be the result of rapid growth of organisms or sudden mortal events. Heterogeneity is also important when looking beyond the modeled boundaries of an ecosystem. What other systems are nearby,

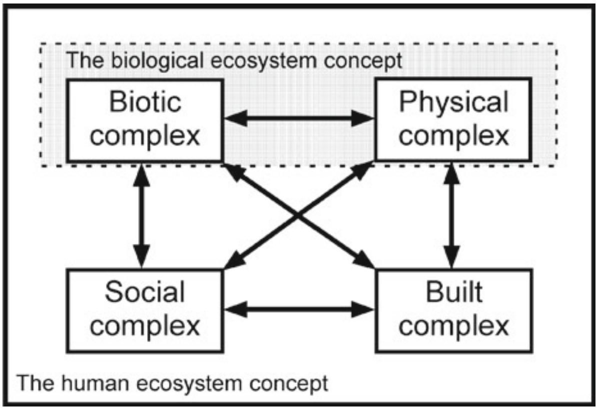

Fig. 23.2 The ecosystem concept of Tansley (*top portion*) with explicit addition of human and constructed elements. Additional pathways of interaction are required by this expansion compared to the original definition of Tansley

and whether the boundaries are permeable or resistant to the fluxes across them are important aspects of heterogeneity. In other words, not only internal but contextual heterogeneity can influence ecosystems (Pickett and Cadenasso 2013).

Fourth, the inclusive ecosystem recognizes humans as components. Such membership can be expressed in several ways. Humans may be internal agents within an ecosystem, responding to and affecting local conditions, pools of resources, and fluxes of resources and wastes. However, human agency may also operate from a distance, as when plumes of pollution from remote sources arrive via water, air, or infrastructure. Human artifacts are also parts of ecosystems. People modify such things as the surface and substrate, and the species composition of managed and unmanaged assemblages. However, they also add built structures and infrastructure (Fig. 23.2).

Finally, the inclusive ecosystem concept is temporally open ended. A model appropriate to such an open-ended conception of systems dynamics has emerged in the form of the resilience loop (Fig. 23.3). This model emphasizes that systems may experience repeated periods of growth and stabilization, disruption, and reorganization (Gunderson et al. 2002a; Holling 2001). Whether such dynamics result in fundamental shifts of a system from one array of states to another is the major concern of the resilience model. This model facilitates answering the question, "Does this system adapt or adjust to changing conditions, or does the system become fundamentally different?" The larger theoretical realm associated with this approach to ecological subjects is that of complex adaptive systems (Holling 2001). The resilience model takes this into account in a powerful way, though one that is still mostly metaphorical rather than mechanistic. This model focuses on system identity as defined by its content and interactive structure, and on whether that identity persists or adapts to internal and external changes (Jax et al. 1998). The ecosystem concept can also accommodate the direct and indirect actions and effects of humans (Pickett and Grove 2009). The original definition by Tansley was accompanied by a discussion of how important people are in ecosystems, and encouraging ecologists to study humans as agents and participants in ecosystems.

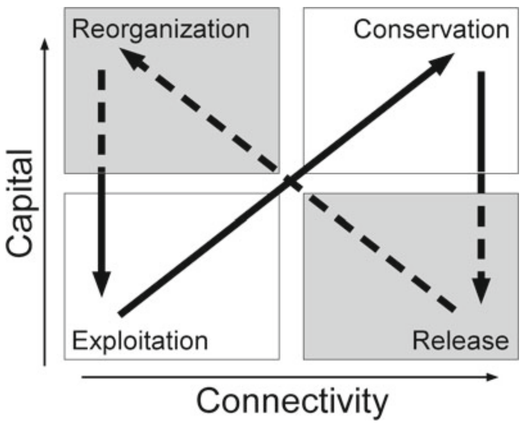

Fig. 23.3 The adaptive cycle of resilience theory. Resilience describes the movement of a system through a conceptual space defined by increase of incorporated resources, or capital, on one axis, and increasing connectivity within the system on the other axis. The *dark arrows* or parts of *arrows* represent the front loop of the cycle, which connects states represented by *white backgrounds*. The *dashed arrows* or parts thereof, represent the back loop of the cycle, connecting states in the *shaded boxes*. The reorganizing phase occurs in a resilient system after disturbance. Reorganization leads to exploitation of readily available resources. The conservation quadrant represents a system shifting to conservative life cycles and retentive material dynamics. The release phase represents the brittleness of a conservative system that is vulnerable to disturbance. This is a framework, not a model that predicts specific compositions or magnitudes of material and energy dynamics. Resilience is represented by the third dimension, or the capacity of the system to occupy both the back and front states of change (Based on Gunderson et al. (2002a))

23.5 Toward Application

The changing internal paradigms in ecology, the inclusive approach to the ecosystem, and the acknowledgement of an overall shift to a non-equilibrium worldview have altered ecology as a science. Contemporary ecology has emerged as "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). This definition still is focused on living things and their actions and products. Some key activities to highlight are these: processes; interactions; and transformations. Key subjects are organisms, energy, matter, and information. Even though the term ecosystem does not appear in the definition of ecology, the new definition is well served by the inclusive conception of the ecosystem. This definition recognizes the breadth of the science, and its focus ranges from systems that are relatively less to those that are relatively more invested with human agency. It also can apply to individual organisms, populations of a single species, collections of many species, landscapes, and regions, as well as ecosystems, as already mentioned.

The definition above is not, however, the only thing affecting the application of ecology. The term ecology itself, along with its included concepts, has many connotations. All important ecological concepts are expected to have three dimensions that affect their application (Jax 2006; Pickett and Cadenasso 2002). One is the core technical definition. Core definitions are clearest when they are stripped down to their conceptual essence. The core definition of an ecosystem has already been mentioned. This definition has been seen to be scale-independent, inclusive of all organisms, and silent about equilibrium, stability, or robustness (Pickett and Cadenasso 2002). Another example can flesh out this idea of definitional generality. Succession as a core concept is simply the change in vegetation structure or composition through time. The definition does not say anything about end points, deterministic pathways, or mechanisms such as facilitation. This dimension of a core, stripped-down definition can be labeled “meaning.”

The reason that meaning or definition is not enough for application is that many details are intentionally left out of the most general articulation of a concept. In order to use any ecological concept, the aspects of the concept that were omitted from the definition must be addressed through models. That is, a concept is *specified* or applied to real, experimental, or simulated situations through the use of models. It is in the models that assumptions about some of the silent details are laid out. The models clarify who the actors are supposed to be, and the kinds of dynamics they are expected to display. Hypotheses are derived from the models about how an aspect of the material world is expected to be structured or to behave under stated conditions. In other words, the models provide the tools that can test the assumptions about the specifics of mechanism, of context, and of behavior (Pickett et al. 2007). For example, in the case of succession, whether the change in a particular plant community is in the direction of increasing dominance by larger statured, slower growing species depends on the presence and frequency of intense disturbances, the availability of resources, and the openness of the area to migration, for example. A more detailed model is required to sort out such factors and the successional interactions that result.

There is a third dimension of any ecological concept: metaphor. Ecological concepts or terms often stand for values and vernacular assumptions about the living world (Larson 2011). Ecology itself can metaphorically stand for diversity, or stability, for example. Metaphorically, the term ecosystem in the public discourse can stand for integration, a discrete place, or a collection of organisms. Succession of vegetation brings to mind a stately, orderly process. The King is dead…. Even the term organism, mentioned with reference to pioneering theories in ecology, can itself be a powerful metaphor that suggests boundedness, integration, homeostasis, and development through an orderly life cycle.

Although metaphor is a powerful opening for conversation among different disciplines or between a science and practitioners, models soon enter as the vessels for empirical clarity, evaluation of claims, and testing hypotheses. Note that many of the attributes of ecological systems and processes embodied in the metaphors applied to them in fact call out assumptions about system structure and behavior. It is models which provide the tools to test such assumptions and to support adaptive application management employing ecological concepts and information. However, there are many cases where application rested on the bridge of metaphor alone, and relevant knowledge about structures, functions, limits, and constraints were not brought across a disciplinary divide. One example is the adoption of the organismal life cycle idea from biotic assemblages into the social ecology of the city (Light 2009). This move, made early in the twentieth century by the Chicago School of sociology was converted to a model of urban blight, and in that form was used to justify such things as mortgage "redlining" in the 1930s and urban renewal in the 1960s. This application resonated long after the initial organismal models of plant succession on which it was based had been challenged and replaced. Absent was a true engagement between the social ecologists and the bioecologists at the University of Chicago, or indeed elsewhere, that might have explored the models beneath the metaphor and alerted the social scientists to the shortcomings of the organismal approach they adapted from biology.

23.5.1 Application and Values

Application demands that values be in play. Some of these will be from society and some reflect the worldview of the science. What scientifically derived values attend the application of contemporary ecology? The prime value might be the respect for data about the actual behavior of ecological systems that challenged the idealized assumptions summarized as the old paradigm (Table 23.1). A second value in play is the desire to generalize across systems and to seek commonality of process. Of course, the fact that I used, without further comment, the word "scientific" in the definition of ecology above implies a set of materialist values about knowledge and its validation. Experts in philosophy and ethics may see other values hiding in the approach I have outlined here.

The relationship of sustainability and resilience may expose a way to think about values in the application of ecology. Sustainability is a socially derived conception that focuses jointly on environmental, social, and economic processes, to ensure that future generations and that people beyond those who benefit most directly from a development are not harmed by or excluded from relevant decision making (Berkes et al. 1994; Curwell et al. 2005; Holling 2001). That set of goals is freighted with values, and appropriately so. However, how is sustainability to be achieved and how is it to be assessed?

Resilience (Fig. 23.3) offers a framework for the mechanisms and the processes that might have to be manipulated and measured in the course of attempting sustainability, say in urban design, or in a resource-management system (Curwell et al. 2005). Whether and to what extent a socio-ecological system is resilient depends on the adaptive capacities within it. Adaptation, following evolutionary theory, is taken as the organizing device. Whether a system can adapt successfully to an internal or externally derived shock depends on such things as social capital, the availability and management of information, and material resources available (Yohe and Tol 2002). The biotic components of adaptive processes include resources, retention mechanisms available for limiting resources, genetic potential, and availability of

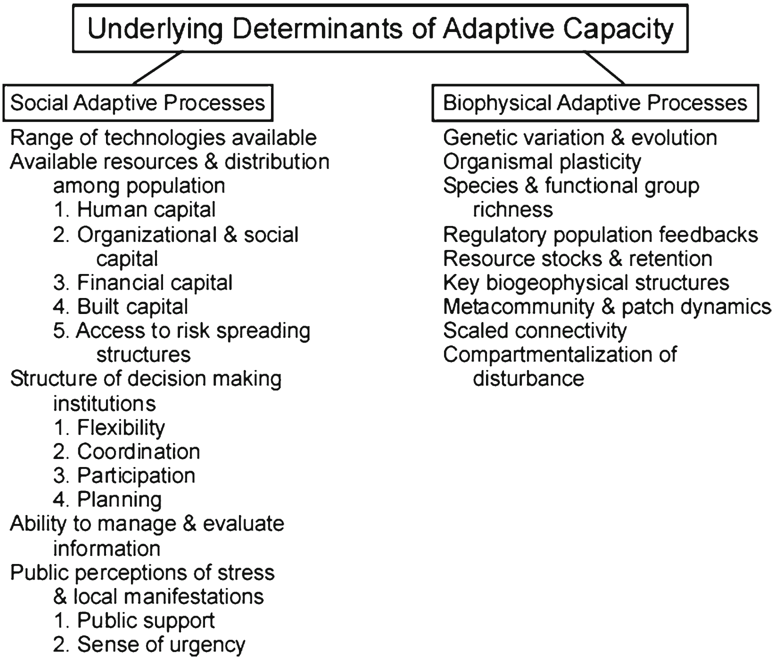

Fig. 23.4 Determinants of adaptive capacity in both social and biophysical realms (Adapted from BES LTER)

post-disturbance colonists (Gunderson et al. 2002b; Walker et al. 2004). Both the social and the biophysical adaptive processes can be summarized (Fig. 23.4). This structure separates the guiding values in a plan for sustainability from the values behind the ecological research to measure resilience and adaptive processes.

Because the issue of application is enmeshed in values, there are some questions that scientists will need help with: Are there norms that are legitimately a part of the paradigms and concepts reviewed here? Are any norms implicit or do they emerge only when the ecological knowledge becomes a part of a social dialog? Are there good and bad norms? What aspects of ecological science affect its relationship to ethics? With these questions in mind, the concerns of this chapter can be summarized.

23.6 The Flux of Nature: A View of Ecological Science

Ecological science may not be what many people think it is (Kolasa and Pickett 2005). It has changed over time. Its textbook generalizations may reflect superseded or challenged worldviews. This chapter has tried to suggest several complexities about the science of ecology that may be important in considering the linkage to ethics.

23.6.1 The Evolution of Ecological Science

Ecology has changed a great deal since its inception roughly a century ago. It has grown from its originally organismal focus to encompass additional scales, new kinds of interaction, and feedbacks among various kinds of units that did not figure in the founding of the discipline (Kingsland 1985, 2005). There is a new paradigm (Table 23.2) that expands the scope of model building and includes many more potentially explanatory factors (Callicott 2002; Pickett 1997). It has expanded explanations from a focus within the systems of interest to their spatial and temporal contexts.

The evolution of the science may not be reflected in the metaphors that are often used to describe it. The new paradigm, for example, is not well described by such cultural labels as "the balance of nature" (Callicott 2002). Because of the material openness of ecological systems, their dynamism over time, and the role of such formerly excluded factors such as disturbance and humans, it may be that there are more effective metaphors to open dialog that includes the newer views of ecology. The new conceptual frameworks and paradigms within the discipline may be poorly served by vernacular descriptions of the science. Models designed to operationalize the general concepts that are so often described in metaphorical terms, may be the crucial nexus for more effective communication among disciplines.

23.6.2 The Evolution of Norms for Application

If nature is in flux, driven by the kinds of events and processes summarized in the resilience cycle (Fig. 23.4), what are the implications for application? First, resilience in and of itself is neither good nor bad. Both desirable and undesirable features of socioecological systems can be resilient. The targets for management, design, and restoration can be informed by ecological knowledge of what is possible and what has been in the past under specific environmental conditions and species rosters.

Second, the norms of application should be examined for resonance with the new paradigm. The new paradigm is a highly generalizable set of statements that open up the formerly narrow assumptions about the structure and dynamics of ecological systems.

Third, points of reference for environmental actions are social choices, hopefully based in part on ecological knowledge about what is possible and what is adaptable. When choosing points of reference for management, restoration, or design, it is important to realize that some points will be less adaptive than others. In fact, it will be possible to choose points of reference that are beyond the physiological tolerances of all the organisms that could constitute a system, or beyond the tolerances of those organisms desired for their role in ecosystem services.

Furthermore, the rates of processes such as generation of genetic novelty, or the migration of species may be slower than the changes in the environmental context. While evolution has manifestly allowed adjustment to changing environments in the past, are the unmanaged evolutionary rates currently achievable adequate to match contemporary environmental change? If not, what are the points of intervention, and what choices are involved in making an intervention? These include economic costs and benefits, and the assessment of direct and indirect effects on other ecosystem services. It may not be possible to maximize all ecosystem services or mitigate all environmental hazards simultaneously.

23.6.3 This View of Life

When Darwin summarized the discovery of natural selection and the conceptual unification and empirical advances that it implied, he referred to a grand view of the process of evolutionary change. Nature was a network of inherited relationships, and contained a source of variation that allowed almost unimaginable diversification and adjustment. It was a striking image that provided a concluding cymbal crash for The Origin of Species (Darwin 1859). Darwin's grand view is ultimately one of flux – ebb and flow – of species against the background of an Earth that they themselves have changed over immense periods of time. That view must now include the rapid changes fomented by human density, behavior, and technology.

The contemporary image of the flux of nature may be a seed for such a grand view of ecology. The founding images of the science emphasized stability and firmness. Flux suggests that the stability is perhaps superficial. What matters most, as embodied in the new paradigm, is the underlying resilience of ecological systems, the degree to which they can adjust to new opportunities or adapt to changing situations.

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