Ecology, Complexity, and Metaphor

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Complexity has recently risen to prominence in ecology as part of a broader interest that suggests its status is something more than just a scientific theory or property of reality. It may be helpful to consider complexity, and related terms such as "self-organization," as recent metaphors deployed to advance knowledge on fundamental questions in ecology, including the relationship between parts and wholes, and between order and disorder. Though not commonly viewed as such, metaphors are an indispensable component of science, and should not be appraised as true or false, but rather in terms of how they help or hinder knowledge. By understanding metaphor as a necessary ally and not a threat to ecological knowledge, we may enrich our contextual understanding of complexity while continuing to invoke it in useful ways. The special section introduced by this article features essays by two prominent experts in ecology, complexity, and metaphor: science studies scholar Evelyn Fox Keller and theoretical ecologist Simon Levin.

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In many ways, ecology has been about the study of complexity since its inception (Bradbury et al. 1996). But complexity has risen to greater prominence in ecology in the last two decades, as evidenced by research initiatives (e.g., the National Science Foundation's "Biocomplexity in the Environment" priority area), targeted journals (e.g., *Ecological Complexity*) and book series (e.g., *Complexity in Ecological Systems,* sponsored by Columbia University Press), and scores of journal and book-length publications and related research conferences.There is no single overarching concept of complexity in ecology, as complexity takes multiple forms in ecological systems (Loehle 2004). A number of concepts, theories, and strategies have been proposed, such as cellular automata (Molofsky and Bever 2004), hierarchy (Allen and Starr 1982), and the notion of ascendancy (Ulanowicz 1997). One of the best-known approaches treats ecosystems as complex adaptive systems (Hartvigsen et al. 1998). Simon Levin, a leading proponent of this approach (1998, 1999), wrote that "ecosystems, and indeed the global biosphere, are prototypical examples of complex adaptive systems, in which macroscopic system properties such as trophic structure, diversity–productivity relationships, and patterns of nutrient flux emerge from interactions among components, and may feed back to influence the subsequent development of those interactions" (Levin 1998, p. 431). In this special section, we hope to provide a broader understanding of this and other views of complexity in modern ecology.

Why has there been such interest in complexity in recent years? Most answers to this question focus on the applicability of complexity to current research and policy questions. As the founding editor of *Ecological Complexity* remarks, "There is an emerging consensus among ecologists and environmental scientists that many of today's urgent ecological and environmental problems across spatial-temporal scales are seen as complex systems problems" (Li 2004, p. 1). More broadly, many classic scientific problems in biology and ecology are now being reexamined from perspectives related to complexity. In one ambitious example, a group of researchers has proposed what has been called biology's "theory of everything" (Whitfield 2001) in claiming that the fractal geometry of an organism's resource-distribution networks can explain a wide range of biological scaling laws (e.g., metabolic rates as a function of body mass).

But interest in—and grand claims based on—complexity are by no means restricted to ecology. Consider the back cover of a popular book on complexity by M. Mitchell Waldrop (1992), which reads, "Why did the stock market crash more than 500 points on a single Monday in 1987? Why do ancient species often remain stable in the fossil record for millions of years and then suddenly disappear? In a world where nice guys often finish last, why do humans value trust and cooperation?" (Waldrop 1992). The answer to all these questions, apparently, is one and the same.

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This potentially enormous cross-disciplinary scope is commonly touted as a major strength of complexity. As Liverpool University's Centre for Complexity Research claims,

> Theories, implications and applications of complexity and complex adaptive systems have grown enormously since the mid-20th century. Emerging out of the natural sciences and increasingly spilling over into the social sciences and arts, they offer a unique interdisciplinary framework for linking the often separate worlds of natural, social and artistic studies, going beyond the unnecessarily rigid boundaries of individual disciplines and exploring the untapped potential of intellectual crossovers and multidisciplinary interaction. (CCR 2005)

But the results of this vast array of interest in complexity are arguably mixed. The bipolar distribution of Amazon.com customer reviews of Waldrop's book suggests that to some, complexity is truly "the emerging science at the edge of order and chaos" (as his subtitle suggests), whereas to others it is yet another fuzzy popularization of technical scientific theory or, perhaps even worse, an entirely vacuous concept. Indeed, as one reads the full range of literature on complexity in ecology, it is striking how the field can, in almost the same breath, cite Robert May (1976) and Fritjof Capra (1982) as founding fathers. Complexity, within and outside ecology, is much more than a scientific theory, and much more than an important empirical property of reality. What, then, is it?

Perhaps we should consider complexity as a metaphor (more properly, a family of related metaphors), the latest in a long series of attempts in ecology to make sense of fundamental questions of pattern and scale (Levin 1992). The Greek root of *metaphor* means "to transfer or carry," and metaphor implies a mapping between two domains, a transfer of one domain onto another to facilitate meaning. We generally think of metaphor in ecology as implying transfer of a technical matter onto a popular substrate—say, notions of a natural enemy (Chew and Laubichler 2003) or a balance of nature (Cuddington 2001). We classify "enemy" and "balance" as metaphorical because they invoke a concrete experiential domain to help understand something more abstract (Lakoff and Johnson 2003). Because we apply these experiential terms literally in everyday contexts, their use in an ecological context seems deviant (hence, metaphorical). However, there are two problems with this interpretation. First, it draws a distinction between everyday and ecological language, when in fact the two are inextricably interwoven, since there is no way to partition the popular and scientific meanings of these terms. Second, it relies on an Aristotelian dichotomy between literal and figurative meaning, one that is questioned by many linguists and philosophers (Hesse 1988, Gibbs 1994).

By questioning these two assumptions, we may instead conceive of metaphors as nomadic terms that link disparate discourses, both public and scientific (Bono 1990, Maasen et al. 1995). In other words, metaphors are not only words that transfer meanings, they also transfer meanings among discourses. Rather than requiring "universal terms with fundamentally stable, proper, and literal meanings" (Bono 1990), metaphors may instead "disrupt stable meanings [and] disseminate meanings across and beyond the boundaries marking a specialized discourse" (Bono 1990). In this sense, complexity may manifest what Peter Weingart and Sabine Maasen (1997), in a metaphoric analysis of the spread of chaos theory, call a "double resonance" arising from the interplay of scientific and popular metaphoric meanings. Double resonance may help explain the slippage between rigorous and speculative applications of a term, which are evidenced in enthusiastic treatments of complexity, such as Waldrop's book, the Liverpool Centre's Web site, or (to choose an example well known to many North American scientists) the work of the Santa Fe Institute.

Complexity may also exemplify how metaphor operates in crucial instances where there is no literal bedrock for our terms. For example, Evelyn Fox Keller has observed that

> scientific research is typically directed at the elucidation of entities and processes about which no clear understanding exists, and to proceed, scientists must find ways of talking about what they do not know—about that [of] which they as yet have only glimpses, guesses, speculations. To make sense of their day-to-day efforts, they need to invent words, expressions, forms of speech that can indicate or point to phenomena for which they have no literal descriptors. (Keller 2002, pp. 117–118)

We suggest that complexity may fill this very role. As an intuition about the world that we can't quite put our finger on, complexity is essentially a placeholder (in a variety of disciplines) for the unknown. While it may seem imprecise, it may for this very reason have a critical heuristic role to play in scientific attempts to understand the world. For example, McShea (1996) set out to make the notion of complexity more operational in order to test the impression (a possible "mass illusion") that it has increased through evolutionary history. In so doing, he helped evolutionary biologists to explicate exactly what they mean by complexity.

With this in mind, we can further elaborate on how complexity incorporates a family of related metaphors. Complexity is an overarching metaphor in that it acts as a placeholder that moves among disciplines whenever they attempt to relate complicated, multifaceted, and unknown or partly unknown phenomena. It also encapsulates a whole family of related, more concrete metaphors, some of which are directly observable and testable. Self-organization, for example, is often explained using Bak's sandpile and its avalanches (both Keller [2005] and Levin [2005] invoke this image). This metaphor is commonly used to capture an array of ideas related to self-organization and complexity. To understand something as abstract as self-organization, we rely on an image with which we are all familiar; yet, at the same time, self-organization is itself metaphoric in the sense described above. That is, Keller (2005) documents how the concept of self-organization has moved between and among contexts (akin to the changes that Weingart and Maasen [1997] document for "chaos"), thereby linking these contexts and allowing new insights in different realms of biology over time.

Biologists invoke other concrete metaphors in their discussions of complexity and self-organization. Keller (2005) discusses how we have understood these phenomena throughout the history of biology in terms of fundamental metaphors, especially understanding organisms as machines and ecosystems as organisms. Levin (2005) discusses problems with the Gaia metaphor, named after the mythical goddess of nature. Each of these concrete metaphors has directly influenced our thinking about more abstract complexity. While complexity may not fit our usual understanding of metaphor (Baake 2003, Keller 2005), it is a critical point of access to our intuitions about the world, one we make sense of with an array of interwoven metaphors.

How does complexity work as a metaphor to help make sense of ecological questions? The issue of the relationship between parts and wholes has been central to ecology over the last century; the concept of emergence has likewise been understood as central in complexity. By, for instance, treating ecosystems as complex adaptive systems and subjecting them to individual-based or cellular automata models, a new understanding arises of ecosystems as wholes that emerge in novel ways from possibly simple, mechanical rules governing interactions among their parts. Ecology has long entertained holism and individualism, at least since the days of Frederic Clements and Henry Gleason (Worster 1994), but complexity offers a suite of metaphoric tools—perhaps novel to our ears, but with distinct meanings nonetheless—that harmonize these long-standing alternative views.

There are two common but partly misguided notions concerning metaphor in science. The first is to view metaphor as a contingent, nonessential part of scientific understanding—often implying that the sooner scientific knowledge is shorn of metaphor, the better. But many studies of science (Baake 2003, Brown 2003), including Keller's studies of biology (Keller 2000, 2002), demonstrate otherwise. One may think of science as primarily empirical (experiments) and formal (equations), but to Keller, much scientific work is inescapably linguistic. She argues, for instance, that metaphor is indispensable to the study of genes, gene action, and genetic programs—and not merely because it provides provisional, figurative language while scientific research moves toward more literal descriptions. Science is an extremely disciplined form of human knowledge production, and if cognitive linguists are correct, metaphor is central to the production of knowledge (Lakoff and Johnson 1999, 2003).

But this raises an even thornier question about the truth status of metaphor in science. Popularizers of ecology have suggested, for example, that mechanistic metaphors of nature, of Earth as a machine, represent a misunderstanding, and that the more correct (and more virtuous) metaphor is that of an organism, a living Earth (Botkin 1990, Abram 1991). But as one of us has suggested elsewhere (Proctor 2001), such broad metaphors are best interrogated in terms of the understandings they afford and those they preclude, rather than in terms of whether or not they are true. As we explain to our Gaia-loving students, though mechanistic ideas may have accompanied practices resulting in massive and often damaging human transformations of nature, we should be grateful for the metaphor of mechanism each time we step onto an airplane—which is designed according to the principles of fluid mechanics to stay aloft. The matter at hand, then, is not so much whether complexity is the correct way to think in ecology, but rather what advantages and disadvantages it entails, what understandings it reveals and obscures. If complexity indeed serves a metaphoric function, does it serve this function well?

If we can acknowledge with Keller that metaphor aids, rather than pollutes, scientific knowledge, then our understanding of why certain metaphors prevail at particular times may be enriched without reducing scientific metaphors to their historical and geographical moments. After all, metaphors are metaphors *of* something, so not just any metaphor will do. Once metaphor is seen as an indispensable ally, a necessary player in our ecological knowledge—and not a cultural trump card or a threat—we may consider how the metaphor of complexity has provided a definitive reading of the relationship between parts and wholes, and between order and disorder, at this particular moment in the history of ecology. For instance, ecologist Michael Barbour has suggested that the transition from support of Clementsian holism to Gleasonian individualism among American ecologists in the 20th century can be explained as much by the changing cultural milieu of post-World War II America, and the internationalization of American ecology, as by the progressive epistemic maturing of ecological science (Barbour 1995). Or consider the wave of interest in chaos theory, and its special take on the relationship between order and disorder, in ecology in the 1980s and 1990s (Worster 1990, cf. Paul 2004). As Katherine Hayles, who studies connections between literature and science, has argued in a book on chaos theory,

> The context that made disorder appear as complex information is not confined to scientific inquiry alone. It is part of a cultural milieu that included World War II, which among other things was an object lesson in the importance of information; consolidation of power by multinational corporations and the accompanying sense that the world was growing at once more chaotic and more totalized; increasing economic interdependencies between nations, which brought home to nearly everyone that small changes could lead to large-scale effects; and rapid expansion of information technologies. (Hayles 1991, p. 7)

The above should not be interpreted to suggest that all questions have been resolved on the interplay of ecology, complexity, and metaphor, but rather that there is an overlap of scholarly concerns, a creative tension possible in thinking of complexity as an ongoing metaphoric chapter in ecology, without succumbing to the polarizing tendencies that would seek to purge metaphor from science or to reduce science to word games. This overlap may best be demonstrated by dialogue between experts coming from plural disciplinary backgrounds. And so the essays that follow have been prepared by two of the most notable scholars in this broad area: Evelyn Fox Keller, professor of the history and philosophy of science at the Massachusetts Institute of Technology, and Simon Levin, Moffett Professor of Biology at Princeton University. Keller's article, "Ecosystems, Organisms, and Machines," offers a history and critique of the concept of self-organization, central to complexity in ecology as developed in the groundbreaking work of Per Bak (1996) and Stuart Kauffman (1995). Levin's article, "Self-organization and the Emergence of Complexity in Ecological Systems," situates complex adaptive systems somewhere between macroscopic-scale concepts, such as Gaia, and microscopic-scale concepts, such as self-organized criticality, as the most suitable metaphor to facilitate adequate explanation—indeed management—of the biosphere's complexity. Levin thereby demonstrates how the complexity metaphor has pragmatic implications, whether or not it is true. Together, the two articles articulate a common ground as well as rightful differences we can expect in the arena of ecology, complexity, and metaphor.

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