

Complex Adaptive Systems, Evolutionism, and Ecology within Anthropology: Interdisciplinary Research for Understanding Cultural and Ecological Dynamics

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We now know that far from equilibrium, new types of structures may originate spontaneously. In far-from-equilibrium conditions we may have transformation from disorder, from thermal chaos, into order. New dynamic states of matter may originate, states that reflect the interaction of a given system with its surroundings. We have called these new structures dissipative structures to emphasize the constructive role of dissipative processes in their formation.

—Prigogine and Stengers 1984:12

A Science of Complex Systems

Recently the ecologist C.S. Holling has discussed the conflict between “two streams of science” and the confusion it creates for politicians and the public (Holling 1995:12-16; see also Holling 1993:553-4). One stream is experimental, reductionist, and narrowly disciplinary. It is familiar to us as the scientific ideal. The less familiar stream is interdisciplinary, integrative, historical, analytical, comparative, and experimental at appropriate scales. Examples given of the first form are molecular biology and genetic engineering. The second form is found in evolutionary biology and systems approaches in populations, ecosystems, landscapes, and global dynamics. One stream is a science of parts, the other a science of the integration of parts.

Anthropology has held itself up to the first stream ideal of science. But the first stream ideal does not always produce the results in anthropology that proponents and critics alike have demanded. Our knowledge of detail is incomplete at societal scales, and prediction can fail. Disproof by experiment is unlikely even with “natural experiments.” And unanimous agreement over results is almost never reached. One response by anthropologists has been to shrink temporal and spatial scales, and hold fast to the ideal; to let the requirements of the scientific methods of this first stream of science structure our research. Anthro-

pologists are often dissatisfied with such restrictions on our object of study, but see little alternative if anthropology is to become a mature science.

But science itself is always evolving. Many anthropologists, both proponents of science and critics, are unaware of the constructive critiques now coming from the mature disciplines of science, from the “hard” sciences. For over twenty years scientists like Holling and Nobel prize chemist Ilya Prigogine (Prigogine 1980, Prigogine and Stengers 1984) have been arguing that the first stream of science is limited to certain problem sets. They contend that a science of complexity has fundamentally different features, and is the proper approach to other problem sets. The subject matter of anthropological inquiry, it will be shown, is commonly addressed in problem sets of the second type. In fact, anthropologists long have argued their case for understanding cultures in terms that sound remarkably like those advocated by the new science of complexity. We have been fighting to resemble the ideal of science, while a second form is coming to look like us.

Points for Anthropology

Holling identifies a number of characteristics of the integrative stream of science. It incorporates technologies and results from reductionist, experimental science, but does not expect disproof by experiment and ultimate agreement by

the scientific community. Models are multivariate and multi-scaled, and testing of alternative hypotheses is done by planned and unplanned interventions into whole systems in case studies, with the evaluation of the integrated consequence of each alternative. Multiple lines of converging evidence are used to argue for one hypothesis over another in a process of peer assessment and judgment.

While these ground rules for research might be revolutionary in the physical sciences, anthropology has long been forced by our subject into this type of science. Case study ethnographies are our hallmark. Experimental disproof is difficult and uncertainty is high. Peer assessment, judgment, and argument—not final agreement—are the norm. We view cultures as integrated wholes, with systemic interrelationships of parts. We make cross-cultural comparisons, extracting multiple lines of converging evidence to bolster our arguments. Each of these characteristics we have been forced to adopt in order to deal with the complexity of culture, and culture-environment interactions.

In addition to these shared fundamentals, the second stream of science incorporates features that are less familiar to anthropologists. In the study of ecosystems or global systems, biota and environment are seen to affect one another at multiple scales and in profound ways. The geophysical environment is not a fixed background for living organisms, it structures and is structured by the presence of life. Only ecosystems-ecological anthropologists have attempted to incorporate this type of insight, and we have been tough critics of ourselves and that effort. Larger scale human-ecosystem interactions were once thought, by anthropologists (and ecologists), to be homeostatic in the short term, and linear and progressive in cultural evolutionary terms. More recently however, advances in theory and research have greatly modified the understanding of the nonlinear dynamics and thermodynamics of biogeophysical evolution (Prigogine 1980; Wicken 1987; Depew and Weber 1995), and of ecosystems (O'Neil et al. 1986; Holling 1986, 1995; Ulanowicz 1986, 1996; Odum 1983, 1996a), and ecological anthropolo-

gists have just begun to make use of the new insights (cf. Adams 1988; Park 1992; Acheson and Wilson 1996; South 1990; Ehrenreich et al. 1995; Gumerman and Gell-Mann 1994; Kohler 1992).

Anthropologists have made some use of multiple scale analysis in the study of culture. We have recognized the need to move away from studying communities as isolates, and toward placing them within global relationships (Bennet 1988; DeWalt and Pelto 1985; Moran 1990). But the study of scale and hierarchy in ecosystems analysis is far more robust than this, and should prove invaluable for understanding the structure and function of human-environment and human-human relationships. The multi-scale, hierarchical relationships that exist in ecosystems require sophisticated methodologies of analysis and ecologists are committed to computer modeling as a central tool. This too diverges from the first stream of science in which modeling is only one tool among many, and anthropologists, specifically, have made little use of computer modeling, especially of the types used now to study complex systems (Lansing's [1991] work is suggestive of the possibilities).

Finally, the expectations and goals of science as advocated by Holling's second stream diverge from the first, and again seem to echo anthropology's past as well as suggest a future. The new stream of science is only weakly predictive. The nature of the dynamics of complex systems makes this so. Surprise and uncertainty are expected, and are important structuring features of evolution in nature. A science of complex systems is then "retrospective and historical" (or retrodictive) in nature. An ecosystem is a "moving target", constantly evolving at multiple spatial and temporal scales. Our knowledge of a system is always incomplete, and surprise is inevitable. We can hope to understand a system's evolution after the fact, but prediction and control, as with biological evolution, is by its nature impossible. Long branded a failing of functionalist and cultural evolutionary theoretical frameworks, incomplete predictability is seen as a fundamental property of complex natural systems.

Comparing Ecological and Social Systems

Ecologists, chemists, physicists, and others from the “hard” sciences, have been eager to apply insights from the new science of complexity to understanding social systems (Allen 1982; Costanza et al. 1993; De Greene 1993; Dyke 1988; Eldredge and Grene 1992; Forrester 1987; Garfinkel 1987; Geyer 1991; Gunderson et al. 1995; Harvey and Reed 1994; Holling 1995; Iberall 1985, 1987; Jantsch 1982; Kahil and Boulding 1996; Lancaster 1989; Loye and Eisler 1987; Maruyama 1982; Nicolis and Prigogine 1989; Odum 1983, 1996a; Ulanowicz 1996). There is a great need for anthropologists to enter into the debate on these issues. Well-established anthropological theory could greatly contribute to better interdisciplinary theory building, and participation by anthropologists would eliminate the tendency to reinvent theory, or to choose a long discredited path. Anthropology represents arguably the best source for social theory that can be applied to this effort. Of the social sciences, anthropology has the time depth, the comparative data, and the bent for evolutionary-ecological-economic thinking that is necessary.

Gunderson et al. (1995), in Holling’s edited volume, is an example of the way ecological systems theory has been applied to social systems. Their understanding of function, hierarchy, and scale in nature is fascinating, incorporating Holling’s now well known theory of ecosystem function (1986) with hierarchy theory (Allen and Starr 1982; O’Neill et al. 1986) into a general model of the dynamics of adaptive systems.¹ In the article, their complex adaptive systems model is applied to understanding rigidity and change in

government wildlife management institutions. They review some relevant social change theories from the social sciences, searching for, and finding, theories or components of theories that appear to mesh with their position.

While this approach seems reasonable, it is too problem specific, focusing on change in management institutions, and omitting the cultural, ecological, and evolutionary context of those institutions. Their choice of social theories is eclectic, settling on theory that is surprisingly un-ecological, temporally small-scaled, and spatially restricted to western style bureaucratic management (i.e., institution and organization theory, risk and decision making). Their theory of complex adaptive systems incorporates a large body of well-studied ecosystem function and process into a general, nomothetic model of system organization and change. It deserves to be wed to nomothetic social theory which is founded on equally well-studied models of cultural process and function. It is at this point that social change theory can then contribute to understanding the specific problems of resource management they wish to address.

Where’s the Ecology?

When the social is borrowed into physical and biological models, it is usually accomplished with cultural models of the familiar, of “entrepreneurs”, and “bureaucracy”, and “management”. The social theory adopted by Gunderson et al. (1995), and by most other ecologists, scientists, and policy makers who have ventured into the game of applying theories of complexity to social systems, is surprisingly un-ecological and un-evolutionary. Most often

¹ In the model, systems in nature continually cycle through the four phases of Exploitation, Conservation, Release (or Creative Destruction), and Reorganization. In ecosystems, r-strategists in the Exploitation phase give way to K-strategists in the Conservation phase. However, as interconnectedness increases, conditions become ripe for chance events such as fire, storm or pest to Release stored nutrients and organized carbon. In the final phase there is Reorganization of (some) released capital and movement towards a next Exploitation phase. Adaptive four phase cycles occur in nature that is hierarchical in space and time. Semi-autonomous levels of adaptive cycles interconnect variables that share similar speed and size relationships. Slow and large levels set the conditions at which faster and smaller levels exits. However the relationship between levels is not simply uni-directional. Fast and small variables in chance conditions can have significant effects on slower levels at critical times in the four phase cycle. An example is insect outbreak that may significantly alter a forest structure if a particular threshold condition has been reached in the forest.

defective human values, uninformed management decisions, undemocratic political systems, or uneducated voters are identified as the cause. Anthropology offers, instead, scientific models of social behavior, of which there are now several approaches that explicitly link social behavior to material-ecological conditions.

Ecologists need the insights of anthropologists for understanding the latent functional and ecological relationships that exist between human culture and the environment and between person and person. Anthropologists, on the other hand, need better understanding of ecological processes from the sub-disciplines of ecology that specialize in complex ecosystem dynamics. O'Neil et al. (1986) make a lucid argument for the power of both ecosystem and community forms of ecology, and the evidence for the vitality of these two traditions is in the great volume of research that they continue to generate. Many of the criticisms of ecosystems models in anthropology (Vayda and McCay 1975; Vayda 1983, 1986; Orlove 1980; Smith 1984) were made prior to the incorporation of recent complex systems thinking into ecology, and no longer apply.²

While some difficulties with ecosystems ecology may remain, Winterhalder (1984: 304) suggests that often critiques have aimed more to advance alternative perspectives (community ecology, evolutionary biology, formalist economics, Marxist economics) than to condemn energy or ecosystem studies per se. Contemporary ecosystems ecology, that now incorporates complex sys-

tems thinking, could be applied in anthropology, not only to questions of subsistence production, but to existing models of political and social organization. Ecological models of function and structure have the potential to inform cultural evolution, political economy, ecosystems anthropology, and other traditions, as we can inform theirs.

Evolutionism in Anthropology

Anthropology's original and most enduring approach to building analytic models begins with the contrast between cultures, in ethnographic cases, which creates the perspective to identify cultural process, structure, and function. Evolutionism in anthropology was born from this comparative method in the late nineteenth century era of Darwin. Under the criteria of the first stream of science, cultural evolution has endured its share of criticism. Lack of specific predictability, properly narrow and controlled experimental design, or immediate applicability to policy problem-solving have been vulnerable spots. These objections themselves are challenged by the second stream of science, in which prediction, control, and simple solutions do not prevail.

The nineteenth century cultural evolutionists, Spencer, Morgan, and Tylor, equated social evolution with human progress, in which the human condition was expected to improve through the replacement of inferior beliefs by those considered superior. This "doctrine of progress" (Sanderson 1990) underlies explanations for the emergence of private property from communal forms, of industrial society from militant

² (1) Homeostatic Systems. A one-time emphasis on equilibrium systems with homeostatic negative feedbacks has been rejected. It is replaced by a focus on evolving patterns of informed thermodynamic flow. (2) The "Calorific Obsession." This criticism is made against single-scale, individual selection, with ingestible calories as the primary limiting factor. Systems of human-environment relations with complex organization at multiple evolving scales have many different limiting resource types—energetic and material. (3) Units of Analysis. Larger "units" in some systems theories (political system, ecosystem, belief system) have been designated from an eclectic set of criteria. The boundaries of dissipative structures are marked by proximate free energy gradients (Wicken 1987), and the energetic "negotiation" of those boundaries is continuous. (4) Typology. Typological or essentialist criticisms of biological systems theory are made principally against deterministic succession models in ecology (Simberloff 1980). Nonequilibrium thermodynamics restricts the determinacy of classical dynamics to limited applications, and replaces it with indeterminacy and evolution in biological and physical processes. (5) Functional Tautologies. Functional explanation needs to be supported by consequence laws at the level of theory (Winterhalder 1984). Evolutionary theory can produce consequence laws for hypothesis testing (ibid.), and an expanded evolutionary theory (Depew & Weber 1988, 1995) addresses evolution at multiple scales, not just individual organisms, which applies it to societal analysis.

society, and of monotheism from polytheism.

At the turn of the century, cultural evolutionary theory began to lose supporters, until it was revitalized by Steward (1955) and White (1949, 1959). This history parallels the fortunes of biological evolutionary theory, which interestingly had declining influence on twentieth century biologists until it was revised in the Modern Synthesis of the 1940's and 1950's (Depew and Weber 1995). Since that time, cultural evolutionary theory has fractured into Evolutionary Ecology (Smith and Winterhalder 1992), Life Histories/ Sociobiology (Chagnon 1988; Hill and Hurtado 1996), Coevolution / Cultural Darwinism (Cavalli-Sforza and Feldman 1981; Rindos 1985, 1986; Boyd and Richerson 1985; Dunnell 1989; Durham 1991), and a line that more directly follows from Service, Morgan, Tylor, Steward and White which is still called Cultural Evolution (Johnson and Earle 1987).

Cultural evolutionary theory of this last form is an analytic tradition within the second stream of science. A recent example of this tradition is *The Evolution of Human Societies* (Johnson and Earle 1987)³, which embodies the positives and pitfalls of this stream of science in anthropology. Following the style of argument employed by prior cultural evolutionists like Steward (1955), Service (1975) and Harris (1977), the authors utilize case

studies of existing and past societies to build arguments for understanding structure and function in cultures, and the processes that create change. What emerges from the comparison and contrasting of cases is a number of hypothesized relationships.⁴ The result of their analysis is to produce explanatory models that functionally relate human social organization⁵, with human political and economic activities, with human subsistence activities, and with human demography.⁶ From the context of those models can be generated functional explanations for other questions, such as Holling's resource management dilemmas. Such social-functional models, that use multiple lines of converging case study evidence, are appropriate and acceptable arguments in the second stream of science, constrained by real limits to generating understanding in complex systems.

Developmentalism and Evolution

It was once argued in anthropology that the process of cultural evolution leads to cultures with increased energy use per capita (White 1959). This position has been criticized for its directionality, its developmentalism, its teleology, its apparent faith in progress. Developmentalism was an early and persistent thread within evolutionary theory, with influential supporters like Lamarck and Spencer. Early biologists who studied embryol-

³ Johnson and Earle (1987) is better recognized as a fusion between cultural evolution and political economy. Their book incorporates political economy's concerns with asymmetrical economic and political power into a theoretical framework that is cultural evolutionary and ecological. Other anthropologists have done the inverse; adopted ecological and evolutionary thinking into a principally political-economic framework, in what has been labeled "political ecology" (i.e., Schmink and Wood 1987; Greenberg and Park 1994). The heart of the functional relationships within the political ecology model are those of political economy, specifically the forces/relations of production, the labor theory of value, and others. The model has been expanded by applying it to contemporary and historical cases in which human-ecological relationships are clearly central to a problem, such as "land tenure" or "environmental quality", however the core functional concerns with the relations of production remain. Johnson and Earle (1987), in contrast, is first and foremost ecological and evolutionary in the tradition of Harris, White, Steward, etc.

⁴ Clearly the authors entered the exercise with theoretical models. It is impossible to begin any human activity without models of the world. Two questions are important here. First, how much detail of the final models existed before the investigation began, and how much emerged from the data itself. And second, were other models tried on the data and then rejected based on the relative merits of the analysis. Bringing to bare alternative models to a problem, evaluation of the results, and choosing among competing explanations are the hallmarks of the second stream of science as advocated by Holling.

ogy and ecologists studying succession found other evidence of directionality in nature.

The Modern Evolutionary Synthesis of the 1940's attempted to replace all notions of directionality in evolution with a statistical model of evolution that emphasized natural selection at the micro-scale of population genetics. Following suit, anthropologists re-wrote their explanations of function and direction in terms that are analogous to individual reproductive fitness. A cost-benefit analysis similar to that used in evolutionary biology is often applied to understanding individual social behaviors. Aggregate culture is seen to be the product of individual behaviors, albeit in an historical cultural context.

At a societal scale, contemporary cultural evolutionists eschew "progress" in function, pointing to the political-economic inequality in culture change which has emerged from the control over productive resources by elites (Harris 1979; Johnson and Earle 1987). World Systems theorists further expand the scope of power asymmetries that cross-cut and integrate cultures into world scale models (Wallerstein 1974; Sanderson 1995).

These insights are significant improvements over earlier progressivist and neocolonial social theory, and are the results of extensive empirical research.

An "Arrow in Time:" Direction and Teleology Reexamined

While these approaches have improved analytic models of direction and function in culture, recent developments in complexity theory (Depew and Weber 1995; Prigogine and Stengers 1984; Bechtel and Richardson 1993; Salthe 1985), in biological evolution (Eldredge 1985; Ereshefsky 1992; Mishler and Donoghue 1992; Wicken 1987), and in ecosystems thinking (Holling 1986; 1995; Johnson 1988, 1992; Odum 1983, 1988, 1996a, 1996b; Odum and Pinkerton 1955; Odum et al. 1995; O'Neil et al. 1986; Ulanowicz 1986, 1994) have argued for function in nature at multiple evolving scales. As in Holling's model of ecosystems, it is argued that function exists in semi-autonomous scales of objects and relationships with similar temporal and spatial characteristics (Figure 1). Biogeophysical processes are argued to self-organize into scales that continuously evolve

⁵ The criticism by anthropologists of functionalism in anthropology has been an important part of our debate (e.g., Friedman 1974; Hallpike 1973; Orans 1974; Gilman 1981), and reflects many of the criticisms of biological evolutionary theory (Gould and Lewontin 1979) and ecosystem theory (Simberloff 1980). The re-orientation of science that is evolving out of the science of complexity (Prigogine and Stengers 1984; Depew and Weber 1995) has deflected much of the debate, and will be discussed here further.

⁶ Johnson and Earle (1987) settle on a population pressure (or stress model) of cultural evolution, the merits of which have been debated for many years in the literature (Cohen 1977; Cowgill 1975; Harris 1979; Haas 1982). The stress of growing populations, it is argued, affects subsistence strategies and technologies, which structure and reflect political-economic and social structural features of a culture. The realization of these relationships is evidenced in their case studies, and, as would be expected, is manifest in variation across cultures, dependent on the vagaries of ecology and history. They repeat a number of anthropology's long argued, and generally well-argued, hypothesized causal relationships (Harris 1979; Boserup 1965; Cohen 1977; Carneiro 1970; Service 1971, 1975), and contribute new insights to that body of theory, although many issues still remain. One is the use of population limits or carrying capacities in constructing evolutionary arguments. Anthropologists have long known that raw population figures are only important in the context of existing economic and technological conditions. However, in addition, many slow- or non-renewable environmental resources can also alter the capacity of an ecology to support a human population. A once supported population size may, over time, come under greater, and greater stress as stores of natural resources are consumed. Population pressure, therefore, is another "moving target" with many limiting factors that may come into play under countless chance historical circumstances. Rather than focusing on population density per se, on some elusive human total (holding technology constant), cultural evolutionists should be constructing or reconstructing a more thorough environmental context, using ecological understanding of how ecosystems (with humans) function and change. The "environment" in "ecological" anthropology must become a dynamic environment, and so with that, we should be applying theoretical models that represent the dynamics of systems. Another fascinating correction to population pressure models is presented in Keegan (1995).

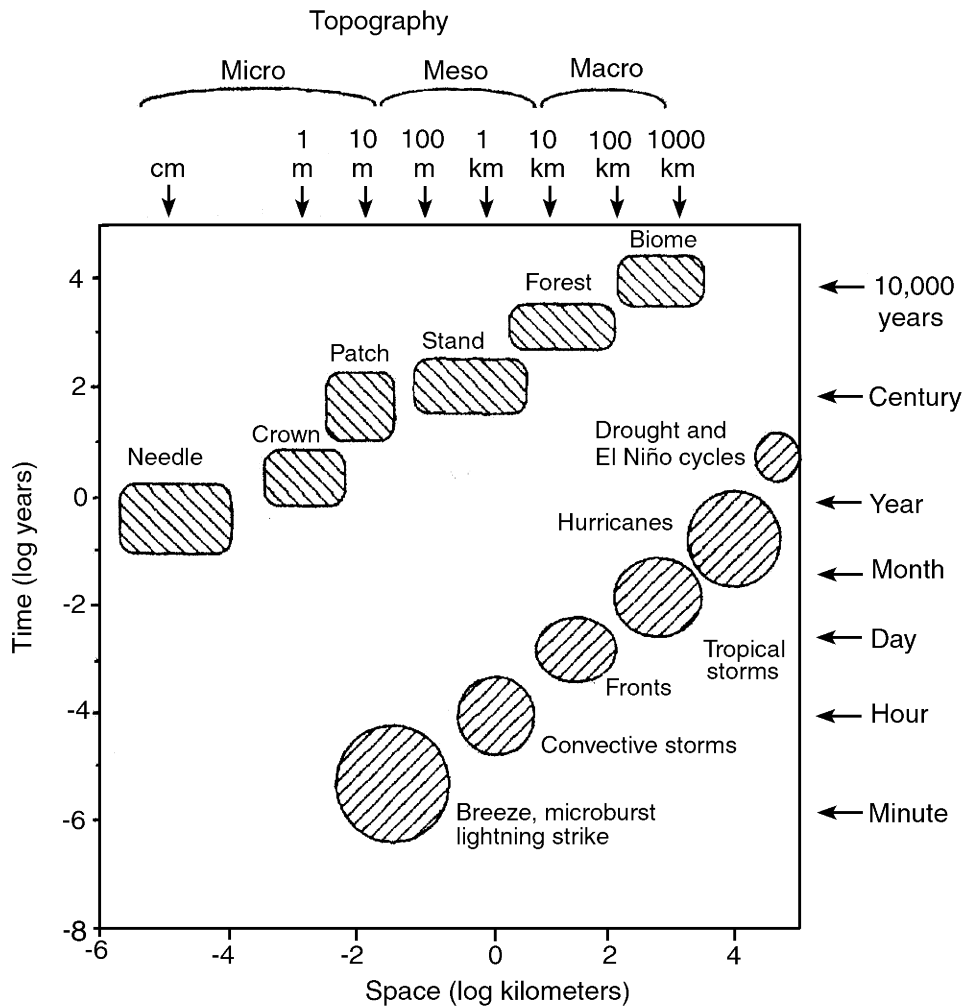


FIGURE 1: HOLLING'S SPACE/TIME HIERARCHY (HOLLING 1995:23; reproduced by permission).

through patterns of destruction and renewal (Figure 2).

With these kinds of insights, there has been renewed interest in the function of nature evolving. Is there functionality, as in White's model, in a scaled and complex nature? In the current research into complex systems, perhaps the most profound conclusion is that nature displays a thermodynamic "arrow in time" (Prigogine and Stengers 1984). Change in nature is irreversible, constructive, and indeterministic due to the Second Law dissipation of energy. While this is intuiti-

ve (watching a plant grow in time-lapse or two liquids form a solution), classical Newtonian dynamics held that time was, in theory, reversible, that nature was finally deterministic, and that outcome could be reduced to the knowable behavior of basic elements of matter. The unarticulated belief in determinism and reducibility in nature has been long a part of our cultural and scientific ethos, and continues to structure much of scientific endeavor.

However, this picture of nature has been abandoned by physicists and chemists in many

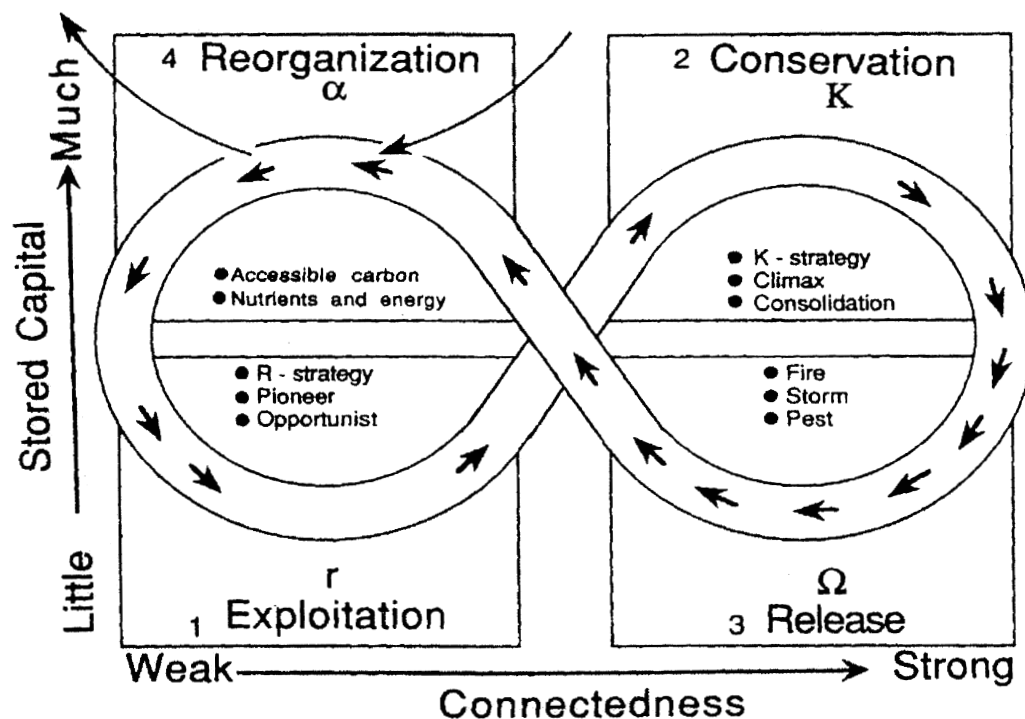


FIGURE 2: HOLLING'S ECOSYSTEM CYCLE (HOLLING 1995:22; reproduced by permission).

problem sets, and been replaced by a model of nature that has structure and is self-organized by the dissipation of energy into what Prigogine calls "dissipative structures." Dissipative structures are the result of the incessant dissipation of energy in open systems. The existence of energy gradients leads nature to create structure. While this may sound teleological, philosophers and scientists have re-addressed the issue of teleology in nature. O'Grady and Brooks (1988), for example, distinguished between goal-seeking behavior (teleological), end-directed behavior (teleonomic), and end-resulting behavior (teleomatic). While "teleological" describes human behavior, nature expresses itself also in teleomatic and teleonomic behavior. "Teleomatic" behavior is said to be the result of the existence of matter and energy, as in gravity, entropic decay, or reaction gradients. It produces end-states, but it is not purposeful, and there is no

"control." "Teleonomic" behavior is the result of evolved internal controlling factors that determine the end-states of processes, as in homeostasis, ontogeny, and reproduction.

Since Darwin, great effort has been made to understand the origin of life, evolution, and development in terms other than teleology. In recent years each of these issues have been addressed by applying the teleomatics of nonequilibrium thermodynamics (Eigen and Schuster 1979, 1982; Wicken 1987; Depew and Weber 1995; Ho and Saunders 1984; Kauffman 1990). In each case, end-directed behavior can be understood to be the product of the end-resulting, teleomatics in nature. The picture that emerges is one in which both physical and biological nature is both creative and in flux, driven by the dissipation of energy. Change is incessant, and the "pause" of species formation, for example, is the event that requires explanation.

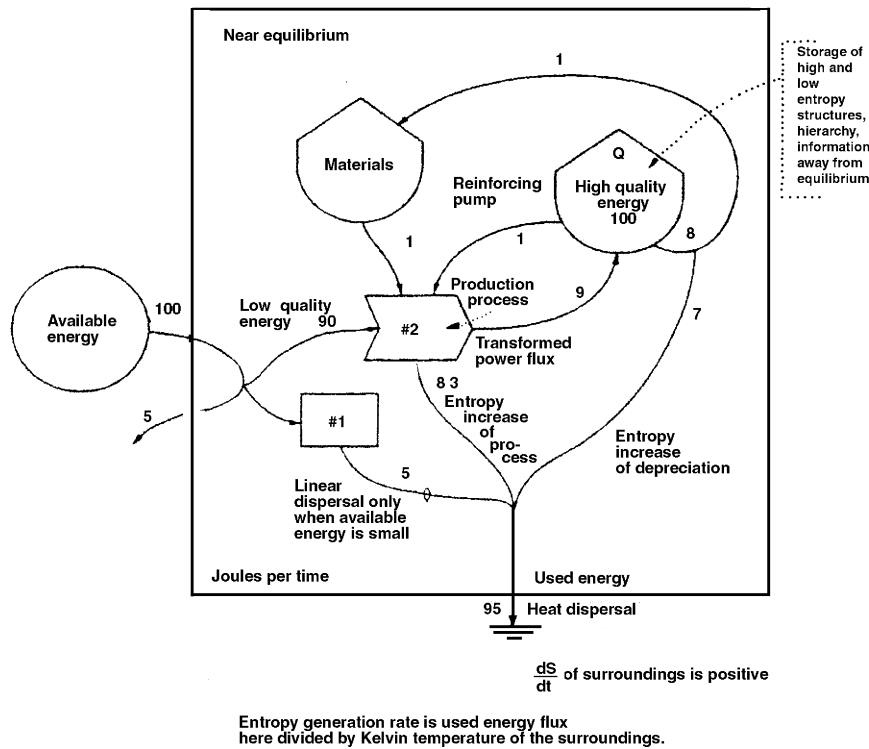


FIGURE 3: ODUM’S SELF-ORGANIZING SYSTEM (ODUM 1995:313; reproduced by permission).

Typical energy flows in one unit of a self-organizing system on a source limited from the outside to a steady flow. Numbers are energy flows (joules) at steady state.

This differs from explanations of stability and change resulting from simple chance, the happenstance coming together of two nucleic acids, then three, leading to a functional strand of DNA, or the monkey jumping on a typewriter and writing Hamlet if given long enough. Nature as depicted

in nonequilibrium thermodynamics is inherently self-organizing and hierarchical. It is argued that matter forms into structures that facilitate the dissipation of energy. Biological life accelerates this process. Cultural life further so.

⁷ Lotka suggested that his “law of evolution” be considered a Fourth Law of Thermodynamics: “Evolution proceeds in such direction as to make the total energy flux through the system a maximum compatible with the constraints” (Lotka 1924:357; quoted in Depew and Weber 1995:409). H.T. Odum has followed Lotka’s work with his principle of Maximum Empower: “In the competition among self-organizing processes, network designs that maximize empower will prevail” (Odum 1996:16). Empower is the flow of emergy per time, and emergy is defined as: “Available energy of one kind previously required directly and indirectly to make a product or service” (1996:13). Emergy is a currency for representing the work that was necessary in the production of a product or service. It represents the energy embodied in that product or service. It is therefore a shorthand means for situating matter and energy within a system. Emergy is the currency that Odum recommends in his brand of ecological economics, called Environmental Accounting (1996).

The Fourth Law?⁷ Maximum Empower

The thermodynamics of this self-organizing process was first discussed by Lotka (1925) and was taken up by systems ecologists (Odum 1983; Ulanowicz 1986) and now by complexity theorists (Johnson 1992; Wicken 1987; Weber et al. 1989). An early promoter of these issues, H.T. Odum has elaborated his position on the energetics of ecosystems and general systems, responding to the surge of research in complex systems in the last 10 years (Odum 1983, 1988, 1996a, 1996b; Odum et al. 1995; Odum and Odum 1997). In Figure 3, one of Odum's systems diagrams depicts the self-organization of dissipative structures, with the formation of autocatalytic feedback ("reinforcing pump"). Nature is understood to organize itself at multiple scales by using energy and materials to build structure, which function to feedback and amplify their capture and use. This autocatalytic relationship has been argued by many researchers since Lotka to be a basic organizing principle in the emergence of life, and the overall organization of nature.

Odum calls this natural phenomenon the Maximum Empower Principle (Odum 1996a:16; see Hall 1995), which is defined in two ways. The first definition addresses the topic of Prigogine's dissipative structures, "Self-organizing systems disperse energy faster, maximizing the rate of entropy production by developing autocatalytic dissipative structures" (Odum 1996a:21). His second definition is the inverse, and emphasizes the constructive side of natural systems, "Self-organizing systems develop autocatalytic storages to maximize useful power transformations" (Odum 1996:20). Over time, this process has led to the evolution of biogeophysical systems that capture, use, and dissipate more of the available solar and earth deep heat energy. This tendency towards increasing dissipation gives nature a directionality that it has lacked in the Newtonian worldview that has long dominated our scientific and popular ethos. More recently it has been shown that this process does not proceed gradually or linearly or lead to equilibrium, but rather it creates fluctuating patterns that we can observe of rapid energy

dissipation followed by longer periods of renewal and storage.

What's Evolutionary about Cultural Evolution?

Whatever else may happen, we are reasonably certain that evolutionary theory will remain incomplete as long as self-organizational and dissipative phenomena are kept at a distance. (Depew and Weber 1995:479)

Anthropologists working in the tradition of cultural evolution have had difficulty linking their work to biological evolutionary theory (Blute 1979; Dunnell 1980), in particular, to the "hardened" Evolutionary Synthesis of this half century, dominated by population geneticists. The advances of complexity theory achieve the inverse, they link biological evolution to a more general definition of evolution, one facet of which is the evolution of culture within ecosystems. Depew and Weber (1995) have evaluated the implications of complexity for evolutionary theory. The scope of their review is vast, spanning many disciplines, which suggests the fertility of interdisciplinary research. The essence of the argument can be summarized.

Complexity theory offers plausible explanations for many of the current challenges to the Evolutionary Synthesis, and it does so within the "basic assumptions" of the theoretical model. Neutral selection, molecular clocks, selfish DNA, hierarchical selection, the emergence of life, the complex genome, ecological succession, punctuated equilibrium—each of these issues has been difficult and cumbersome at best to articulate with the Synthesis and its exclusive concern with natural selection at the scale of organisms. Complexity theory places organisms within a rendering of nature that is hierarchical and self-organizing at multiple temporal and spatial scales. Physical selection ("survival of the stable") and chemical selection ("survival of the efficient") are related to natural selection by these processes (1995:408). In this context, the evolution of life is not a "frozen accident," but an explicable elaboration of a basic theme, although irreducibly and historically contextualized. Not surprisingly still, life is expected to be further organized into species and ecosystems that exhibit global, emergent properties.

Cultural evolution since its beginnings has addressed itself to the emergence of social properties. Patterns of social self-organization and historic re-organization have been the focus of numerous case study-driven evolutionary scenarios. Using case studies of pre-historical, historical, and extant human groups, anthropologists produced evolutionary typologies (i.e., band, tribe, chiefdom, state) and processual models which have aimed to relate them. Recent processual models of cultural evolutionary change, such as Johnson and Earle's (1987), have emphasized the interplay between the human-ecological environment, human demographics, technological innovation, and political-economics. The emergence of novel cultural phenomena (but not the means of evolutionary transmission and selection so heavily emphasized by the biological evolution of the Synthesis) has been the dominant focus of explanatory theoretical models. Examples of emergent properties of culture that have occupied cultural evolutionists include the following:

- The emergence of food production technologies and domestication.
- The emergence of labor specialization.
- The emergence of private property.
- The emergence of large, permanent human social groups.
- The emergence of social inequality, related to the asymmetrical control of the productive resources and technologies by factions within a society.
- The emergence of organized warfare and specialized coercive military/police institutions.
- The emergence of markets and the expansion of trade.
- The emergence of political chiefs and chiefly lineages.
- The emergence of institutionalized religion and religious specialists.
- The emergence of irrigation agriculture.
- The emergence of legal/financial/monetary technologies.
- The emergence of state bureaucracy.
- The emergence of modern world systems, and supranational legal/financial institutions.

As emergent cultural behaviors have been identified and situated historically, cultural evolutionists have worked to relate cultural patterns into functional-ecological explanatory models. Cultural evolutionists have asked why cultural properties have emerged, what ecological, demographic, technological, and economic factors might have set the stage for their appearance, and how cultural properties functionally interrelate with others. They have attempted to explain emergent cultural properties in material ways, which is similar to the methods ecologists use to describe ecosystem function and organization, and the transitions between multiple, functionally stable ecosystem states.

Some anthropologists have recently sought to improve cultural evolutionary theory by strengthening ties to biological evolution (Boyd and Richerson 1985; Cavalli-Sforza and Feldman 1981; Rindos 1985, 1986; Durham 1991). The direction of this effort has been heavily influenced by population genetics. Unfortunately, this component of the Synthesis is arguably the most reductionist. The anthropology that it spawns is equally reductionist, intent on decomposing symbolic culture into traits that can be manipulated by mathematical formulation. This is occurring in anthropology at a time when the synthesis has come increasingly under pressure, and an expanded synthesis is emerging that emphasizes the developmental, ecological, hierarchical, integrative, and historical aspects of nature. This version of cultural evolutionary theory appears to be moving in the opposite direction.

This is particularly unfortunate considering the ease of fit between the long-standing version of cultural evolutionary theory, e.g. Johnson and Earle (1987), and this expanded synthesis. The evolutionary theory emerging from the science of complexity does not require structures analogous to genes at multiple physical, chemical, ecosystem, or cultural scales. To the contrary, the evolution of language and culture have tremendously flexible capacities for information storage that are qualitatively different from genetic representation. Cultural evolutionary theory, in the tradition of Johnson and Earle (1987), that emphasizes emer-

gent cultural and structural properties, exhibiting internal dynamics and organization, and integrated to ecological systems by the self-organizing processes of energy capture and dissipation is a better match to an evolving Darwinism.

Cultural Evolution from an Ecology of Complexity

In all the scales of the known universe, from atomic processes to the stars, pulsing oscillations appear to be the norm. (Odum 1996a:16)

Anthropologists and other scientists are beginning to apply complex systems theory to social theory. The biological and physical scientists have approached the problem from numerous perspectives and with uneven degrees of social science sophistication (Allen 1982; Costanza et al. 1993; De Greene 1993; Dyke 1988; Eldredge and Grene 1992; Forrester 1987; Garfinkel 1987; Geyer 1991; Gunderson et al. 1995; Harvey and Reed 1994; Holling 1995; Iberall 1985, 1987; Jantsch 1982; Kahil and Boulding 1996; Lancaster 1989; Loye and Eisler 1987; Maruyama 1982; Nicolis and Prigogine 1989; Odum 1983; Ulanowicz 1996). Archaeologists have recently become interested (Kohler 1992, Gumerman and Gell-Mann 1994), especially for applying the non-linear, or pulsing dynamics of complex systems to understanding the collapse of state societies (Tainter 1988, Yoffee and Cowgill 1988). Fewer cultural anthropologists have found use for complexity (Lansing 1991, Acheson and Wilson 1996, Park 1992, Carniero 1982), and their works often reflect the mathematical components of the model, missing the potential value of its thermodynamic and ecological underpinnings.

In cultural anthropology, R.N. Adams (1988) produced a groundbreaking and extensive synthesis of much of complexity theory with anthropology, particularly into cultural evolutionary theory and into political anthropology. His book is perhaps the most thorough discussion to date, but falls short on some accounts. Adams has at-

tempted to incorporate many of the issues raised by complexity theory, which include Lotka's energy principle, dissipative structures, hierarchical organization, and others. His is an effort to extend complexity theory into the obvious next-frontier of human culture. He chooses, however, to concentrate his theory building on the emergence of political power and social hierarchy, and does not pursue his own arguments into detailed analysis of human-environment relationships and the complex ecological context of culture. By this strategy, he misses some important opportunities to better utilize the implications of ecological theory for cultural evolution.

While Adams' research program is insightful and fertile, the synthesis can be improved by more completely and thoroughly integrating understanding of larger-scale ecosystem structure and function, within which human organization occurs. More specifically, the critical issue that needs to be incorporated is resource capture, use, and re-use in ecosystems with humans.

Natural Resource Use and Re-Use in Ecosystems with Humans

According to Odum (1983), global environmental systems self-organize around renewable energy use, which originates with solar energy and earth deep heat, and which fuels weather and geologic systems, and ultimately ecosystems. This self-organization results in ecosystems that exhibit pulsing between storage and release of energy in the form of nutrients, biomass, populations and information (Odum 1996a, 1996b; Odum et al. 1995). This storage and release occurs at multiple spatial and temporal scales. From our human scale, therefore, we perceive some storages as renewable, such as fresh water in lakes, or annual grasses, or seasonal insect populations. Other storages, however, we perceive as slow-renewable, like topsoil, or forest trees, which can be consumed by intensive human use, fire, flood, or some other action, and require many years to return.⁸ At our scale we often call these disasters, but it is becoming increasingly recognized that pulsing is a part of self-organizing ecosystems on a larger scale, as in the

many known fire-adapted ecosystems. Other storages we perceive as non-renewable, such as fossil fuel, or metals (although these too are part of renewable geologic cycles at a larger time scale). All life, at any scale, is said to organize around these renewable, slow-renewable, and non-renewable stores of energy and resources.

Slow-renewable resources have set real limits to the growth of human populations in pre-history and historical times (Odum and Odum 1997, Adams 1982, Debeir et al. 1991, Perlin 1991, Hardin 1993). Important resources are topsoil, wood, metals, stone, reefs, and others. The consumption of these storages of solar and earth energy have been implicated in the expansion of state societies, in their collapse (Culbert 1988, Tainter 1988), or less dramatically, in the waves of use and abandonment of landscape by swidden agriculturalists, pastoralists, or hunter-gatherers. Humans are not alone in being constrained by resources. Put more generally, pulses at larger and smaller temporal and spatial scales, will limit the size of all biological populations. This occurs locally to human populations, and has also occurred more globally at times (i.e., plague, drought, earthquakes, El Niño, hurricanes). The human difference is that at short temporal scales (in evolutionary time) we have modified our ability to capture and use additional environmental storages of resources, and our global population size has pulsed to its current large number.

Understanding environmental resources in these terms provides a more thorough model of ecological dynamics for cultural evolutionists. It indicates motive for human movement on the landscape, and for resource intensification when movement is not possible or undesirable. This dynamic produces a different picture of the environment, one far from homeostatic, one that should be expected to put stress on human populations from time to time. Under the stress of pulses from scales both slower and faster than human temporal scale, resource intensifications would at times be in great

demand. With resource intensifications comes population growth and the "closing of doors" to prior, lower-density strategies like hunter-gathering, which since Boserup (1965) has been central to cultural evolutionary thinking about the environment.

Framing now the issue of resource use and population growth in terms of self-organization and dissipative structures leads to another perspective on this important relationship between humans and resource use in cultural evolution. As defined in the Maximum Empower principle above, and observed in autocatalytic growth cycles, systems that use energy to build structure are often "rewarded" by gaining access to more energy. Human action in agricultural intensification builds structure that captures more energy by utilizing storages of slow-renewables like topsoil, non-renewables like phosphate and oil, and renewable energy. Our use of storages makes possible the capture of more energy for growing more of us. The human-agriculture ecosystem is energetically rewarded and expands to cover more landscape because it taps resource storages that were previously unused. In macro energetic terms, this human system incorporates or replaces other systems because it captures and dissipates more energetic resources.

Where are the limits? The limits are in the storages. Netting (1993) has shown in great detail the incredible diversity and ingenuity of small-holder farmers in capturing slow-renewables and renewable resources, and their efforts to maintain them. These elaborate systems have evolved because of the limits imposed by natural ecosystems. New production strategies and technologies have been the human response to limits, and they have come in two principal forms. The first is the intensive use of human labor. However, the obvious limit to that strategy is that it rewards the production of new labor, more people, which eventually pushes on the limits of the landscape to expansion. The other complementary strategy is to cap-

⁸ It may be difficult for some to think of topsoil as a resource that is consumed. But topsoil is an organic product in ecosystem growth, and its nutrients can be captured and removed by farming, unless explicitly replaced.

ture additional storages of resources, which requires new technologies, and is slower in coming due to chance events and prior technologies. This century especially has shown the greatest return to this strategy, to the point that we are now essentially "eating oil" (Green 1978). However, other technologies have been extremely important historically in gaining access to new resources, particularly plows for access to deeper soils, axes for opening up forest topsoil to farming, draught animal technologies, water delivery systems, storage facilities, iron and steel smelting, and others.

Does cultural evolution lead to more energy per person? Cultural evolution should not produce more energy that is captured and controlled by each culture member. The capture and use of resources is systemic, and results in more people, some with less energy than members of less complex cultural systems. According to this theoretical model, the teleomatics of nature have resulted in the emergence of life, which has now resulted in the emergence of human culture. The emergence of both was entirely unpredictable from the start, and both exist only in an historical context that channels any future evolution.

Does this argue for the progressive and inevitable rise of civilization in energetic terms? Again no, for the increased capture and use of resources by humans has been a halting process, not continuous, following environmental pulses at larger scales, and technology induced human pulses and contractions. Dissipative structures are argued to evolve only because they can. Odum contends that we are currently entering a period of contraction, in energetic terms, due to diminishing returns on fossil fuel use, and there is no evidence that a new technology can give nearly the same return that oil did in its years of high energetic return (Odum and Odum 1997). It is expected now that improved efficiency, materials recycling, and a concentration on maintaining renewable resources will need to be the strategy for a desirable standard of living.

Science-Lead or Science-Normalized?

Expressions of frustration from members of the scientific community with the use of science, or lack thereof, in forming national policy are ubiquitous. Holling, for example, calls the growth of rigidity and unresponsiveness in management agencies a "pathology of management." National scientists, in our nation and in others, are routinely ignored by national governments, despite national and international support for the quality of their research and conclusions, as in the long medical battle against smoking in this country. Scientific research condemning deforestation and resettlement in the Brazilian Amazon in the 1980s, conducted by Brazilians (Fearnside 1986), for example, was applauded nationally and internationally, but out-of-hand ignored in final policy decisions. In fact, the pattern of scientific involvement in policy, as in Amazon "resettlement," often follows the sequence of policy decision, then scientific assessment of consequences. In Holling's case of forest management in New Brunswick, science (or better said, new technologies) led to a pattern of forest timber intensive exploitation. Holling has recounted how forest management policy, once set in motion, became rigid and self-maintaining, leading to surprising environmental catastrophe when chance events later occurred.

Cultural evolutionary models would interpret the situation differently, beginning by placing "science" and "management" in the context of state societies and world systems. State societies are inherently hierarchical, with political and economic power concentrated among a minority of elites. What is shared by most recent accounts of the evolution of state societies⁹ is a focus on the intensification of production, which co-evolves with the unequal control of productive resources, and which is buttressed by legal and coercive (police, military) institutions. Whatever else it does, the concentration of capital in state societies makes possible the production of resource intensive products, such as oil tankers or automobiles or armies,

⁹ The evolution of culture leading to state societies has been long studied in anthropology, and has led to a number of theoretical reconstructions (Johnson and Earle 1989; Harris 1979; Service 1971, 1975; Fried 1967, 1978; Carneiro 1970; Cohen 1977; White 1959; Steward 1955; Morgan 1877; see Sanderson 1990 for a current review).

which feedback to produce state societies that are the most exploitative of energetic resources that the world has ever seen. While other social relations of production are conceivable, none has occurred that could compete with capitalism in these terms. Stated otherwise, perhaps capitalism was the first “technological” innovation of its capacity for production and consumption, and others could never overcome the “first cover” advantage.¹⁰

In this context it can be asked whether science leads the evolution of capitalist state societies? The discourse of “scientific progress”, that was emergent with capitalism, tells us that it does. The cultural evolutionary argument, however, suggests that technological innovations are an extremely desirable answer to resource and population stress, because they can alleviate both in the short term, and simultaneously enhance the political and economic power of elites who control the technologies. The case of the steam engine in the last century is instructive because it flourished as a productive technology for 50 years before the science existed to explain it. In other cases, scientific knowledge exists (we have the know-how to land people on Mars), but it is not being put to use. Production and productive technologies co-evolve. Stated in terms of complex systems, however, neither science nor technology lead the evolution of the state, but rather both will always be entrained to the current production context.

Within this evolutionary model, concepts like “management institutions” can also be placed in functional relationships. The rewards to economic production underwrite the state apparatus. Therefore, the evolutionary model suggests that states will provide an economic environment that fosters production, that management institutions

will evolve to promote economic growth when growth is possible. The growth of production is dependent on access to productive resources. The first priority of state institutions, it can therefore be expected, will be to make those resources available by whatever means in their power- legal, economic, or coercive.

Given these considerations, the resource management practices encountered by Holling are not “pathological.” They were not motivated by science either. They were driven by the available technologies for resource exploitation. They were motivated by the same demands that have motivated all state societies. Why has science now been brought into the equation by state and private interests? Because the resource is threatened. The same question should always be asked when science is funded by national governments. Why, for instance, are ecological issues the world over now gaining their greatest audience in history, lead today by the discourses of “sustainable development” and “biodiversity conservation,” when much of the science that supports them has been available for decades? For many reasons, but probably the most important is the growing threat to world ecosystems, and therefore world productive systems.¹¹

Looking at these issues in recent historical terms, why then did science and management bureaucracy balloon in the 1960s and 1970s, only now to be pruned in the name of efficiency? Following the ecological and cultural evolutionary argument made to this point, it grew because it was able to. The fossil fuel technologies that emerged from World War II were extremely productive, in energetic terms. However, if Odum is accurate, the world returns on that productive strategy are flattening out, and will eventually decline.

¹⁰ “First cover,” also known as “lock-in” is an ecosystems concept. It refers to the fact that in succession it is often the first plant species to enter or “cover” an open niche that will be successful at a point in time, regardless of some absolute measure of efficiency. This emphasizes the stochastic nature of ecological and evolutionary thinking in the creation of historical scenarios of change in complex systems.

¹¹ Escobar (1996) discusses this issue from the perspective of a “poststructuralist” political ecology. Both models see the expansionary nature of capitalism, the “logic of reckless capital” in his terms, as the immediate cause. The evolutionary-ecological model, however, sees the current crisis of capitalism as imposed by a contracting resource base, while Escobar looks first to the so-called contradictions of capitalism.

This should be expected because the current world economy is ultimately dependent on finite storages of fuel and other resources.

Should we be concerned? If we believe that social science will be a useful tool for maintaining a reasonable standard of living in a contracting world economy then we should be worried. The current neoliberal "reforms" are producing a market academia that can pay its way. These reforms reward the "hard" sciences and technology, and penalize the social, humanistic, and critical traditions of knowing, because of their uncertain returns to investment. This suggests clearly the tight interconnectedness of academics with the current productive strategy. However, it also indicates the current inability of the social sciences to demonstrate its potential for understanding the current dilemma.

Conclusions

Understanding science and government in terms of analytic models of cultural evolution does not lead to political or academic inaction or resignation. To the contrary, it should be clear by now that the application of complexity theory to evolution, both biological and cultural, suggests the indeterminacy of nature, and the central role of chance and action. Appreciation of the physical limits to growth is sobering, but it is essential for directing science and society to deal with the fuller nature of our world social and ecological dilemmas. Appreciation of the functional interrelationships within culture, and between culture and environment, is needed to frame the debate and inform decision making.

Science-minded anthropologists (and other scientists) continue to be influenced by the methods associated with the reductionist stream of science, and by the expectations of mechanistic explanations and control, to focus on simple problems with single or very few independent variables, essentially to abandon the study of the organization of emergent variables (such as economic sector organization, or human-environment dynamics), which for many years sustained anthropology and set it apart from other sciences.

Complexity theory and its expanded evolutionary synthesis can be integrated into cultural evolution and ecological anthropology. Theory building of the type best known to cultural evolutionists, of mounting processual arguments based on case study evidence, is not an evolutionary dead end. The type of science now emerging from the study of complex systems indicates that anthropology has much to contribute to the interdisciplinary study of complexity in natural systems.

References Cited

- ADAMS, R. N.
 1982 *Paradoxical Harvest*. Cambridge: Cambridge University Press.
 1988 *The Eighth Day: Social Evolution as the Self-Organization of Energy*. Austin: University of Texas Press.
- ACHESON, J. M., AND J. A. WILSON.
 1996 Order out of Chaos: The Case for Parametric Fisheries Management. *American Anthropologist* 98(3):979-594.
- ALLEN, P. M.
 1982 "Self-Organization in the Urban System," in *Self-Organization and Dissipative Structures: Applications in the Physical and Social Sciences*. Edited by W. C. Schieve and P. M. Allen, pp. 132-158. Austin: University of Texas Press.
- ALLEN, T. F. H., AND T. B. STARR.
 1982 *Hierarchy: Perspectives for Ecological Complexity*. Chicago: University of Chicago Press.
- BECHTEL, W., AND R. C. RICHARDSON.
 1993 *Discovering Complexity: Decomposition and Localization as Strategies in Scientific Research*. Princeton, NJ: Princeton University Press.

- BENNETT, J. W.
1988 "Anthropology and Development: The Ambiguous Engagement," in *Production and Autonomy: Anthropological Studies and Critiques of Development*, Monographs in Economic Anthropology, No. 5. Edited by John W. Bennett and John R. Bowen, pp. 1-29. Lanham, MD: University Press of America.
- BLUTE, M.
1979 Sociocultural Evolutionism: An Untried Theory. *Behavioral Science* 24:46-59.
- BOAS, F.
1938 *The Mind of Primitive Man*. New York: Macmillan.
- BOSERUP, E.
1965 *The Conditions of Agricultural Growth*. Chicago: Aldine.
- BOYD, R., AND P. J. RICHESON.
1985 *Culture and the Evolutionary Process*. Chicago: The University of Chicago Press.
- CARNEIRO, R. L.
1970 A Theory of the Origin of the State. *Science* 169:733-738.
1982 "Successive Reequilibrations as the Mechanism of Cultural Evolution," in *Self-Organization and Dissipative Structures: Applications in the Physical and Social Sciences*. Edited by W. C. Schieve and P. M. Allen, pp. 110-115. Austin: University of Texas Press.
- CAVALLI-SFORZA, L. L., AND M. W. FELDMAN.
1981 *Cultural Transmission and Evolution: A Quantitative Approach*. Princeton: Princeton University Press.
- CHAGNON, N. A.
1988 Life Histories, Blood Revenge, and Warfare in a Tribal Population. *Science* 239:985-93.
- COHEN, M. N.
1977 *The Food Crisis in Prehistory*. New Haven: Yale University Press.
1978 "Population Pressure and the Origins of Agriculture: An Archaeological Example from the Coast of Peru," in *Advances in Andean Archaeology*. Edited by David L. Browman, pp. 91-132. The Hague: Mouton Publishers.
- COSTANZA, R., L. WAINGER, C. FOLKE, AND K. GORAN MALER.
1993 Modeling Complex Ecological Economic Systems: Toward and Evolutionary, Dynamic Understanding of People and Nature. *BioScience* 43(8):545-555.
- COWGILL, G. L.
1975 On the Causes and Consequences of Ancient and Modern Population Changes. *American Anthropologist* 77:505-525.
- CULBERT, T. P.
1988 "The Collapse of Classic Maya Civilization," in *The Collapse of Ancient States and Civilizations*. Edited by N. Yoffee and G. L. Cowgill, pp. 69-101. Tucson: University of Arizona Press.

- DEBEIR, J., J. DELEAGE, AND D. HEMERY.
1991 *In the Servitude of Power: Energy and Civilization through the Ages.* London and New Jersey: Zed Books.
- DE GREENE, K. B.
1993 Evolutionary Structure in the Informational Environmental Field of Large-Scale Human Systems. *Journal of Social and Evolutionary Systems* 16(2):215-230.
- DEPEW, D. J., AND B. H. WEBER.
1988 "Consequences of Nonequilibrium Thermodynamics for the Darwinian Tradition," in *Entropy, Information, and Evolution: New Perspectives on Physical and Biological Evolution.* Edited by Bruce H. Weber, D. J. Depew, and J. D. Smith, pp. 317-354. Cambridge, MA: MIT Press.
1995 *Darwinism Evolving: Systems Dynamics and the Genealogy of Natural Selection.* Cambridge, MA: MIT Press.
- DEWALT, B. R., AND P. J. PELTO, EDITORS.
1985 *Micro and Macro Levels of Analysis in Anthropology: Issues in Theory and Research.* Boulder and London: Westview Press.
- DUNNELL, R. C.
1980 Evolutionary Theory and Archaeology. *Advances in Archaeological Method and Theory* 3: 35-99.
1989 "Aspects of the Application of Evolutionary Theory in Archaeology," in *Archaeological Thought in America.* Edited by C. C. Lamberg-Karlovsky. Cambridge: Cambridge University Press.
- DURHAM, W. H.
1990 Advances in Evolutionary Culture Theory. *Annual Reviews of Anthropology* 19:187-210.
1991 *Coevolution: Genes, Culture, and Human Diversity.* Stanford: Stanford University Press.
- DYKE, C.
1988 "Cities as Dissipative Structures," in *Entropy, Information, and Evolution: New Perspectives on Physical and Biological Evolution.* Edited by Bruce H. Weber, David J. Depew, and James D. Smith, pp. 355-367. Cambridge, MA: The MIT Press.
- EHRENREICH, R. M., C. L. CRUMLEY, AND J. E. LEVY, EDITORS.
1995 Heterarchy and the Analysis of Complex Societies. *Archaeological Papers of the American Anthropological Association*, Number 6. Washington DC: American Anthropological Association.
- EIGEN, M., AND P. SCHUSTER.
1979 *The Hypercycle.* Berlin: Springer-Verlag.
1982 Stages of Emerging Life: Five Principles of Early Organization. *Journal of Molecular Biology* 19:47-61.
- ELDREDGE, N.
1985 *Unfinished Synthesis: Biological Hierarchies and Modern Evolutionary Thought.* New York: Oxford University Press.
- ELDREDGE, N., AND M. GRENE.
1992 *Interactions: The Biological Context of Social Systems.* New York: Columbia University Press.

- ERESHEFSKY, M.
1992 *The Units of Evolution: Essays on the Nature of Species*. Cambridge, MA: MIT Press.
- ESCOBAR, A.
1996 Construction Nature: Elements for a Post-Structuralist Political Ecology. *Futures* 28(4):325-343.
- FEARNSIDE, P. M.
1986 Spatial Concentration of Deforestation in the Brazilian Amazon. *Ambio* 15(2):74-81.
- FORRESTER, J. W.
1987 Nonlinearity in High-Order Models of Social Systems. *European Journal of Operational Research* 30:104-109.
- FRIED, M. H.
1967 *The Evolution of Political Society: An Essay in Political Anthropology*. New York: Random House.
1978 "The State, the Chicken, and the Egg; or What Came First?" in *Origins of the State: The Anthropology of Political Evolution*. Edited by R. Cohen and E. R. Service, pp. 35-47. Philadelphia: Institute for the Study of Human Issues.
- FRIEDMAN, J.
1974 Marxism, Structuralism and Vulgar Materialism. *Man* 9:444-469.
- GARFINKEL, A.
1987 "The Slime Mold Dictyostelium as a Model of Self-Organization in Social Systems," in *Self-Organizing Systems: The Emergence of Order*. Edited by F.E. Yates, A. Garfinkel, D.O. Walter, and G.B. Yates, pp. 181-212. New York and London: Plenum Press.
- GEYER, F., EDITOR.
1991 *The Cybernetics of Complex Systems: Self-Organization, Evolution, Social Change*. Salinas, CA: Intersystems.
- GILMAN, A.
1981 The Development of Social Stratification in Bronze Age Europe. *Current Anthropology* 22(1):1-23.
- GOULD, S. J., AND R. C. LEWONTIN.
1979 The Spandrels of San Marco and the Panglossian Paradigm: A Critique of the Adaptationist Programme. *Proc. R. Soc. Lond.* 205:581-598.
- GREEN, M. B.
1978 *Eating Oil: Energy Use in Food Production*. Boulder: Westview Press.
- GREENBERG, J. B., AND T. K. PARK.
1994 Political Ecology. *Journal of Political Ecology* 1:1-11.
- GUMERMAN, G. J., AND M. GELL-MANN, EDITORS.
1994 Understanding Complexity in the Prehistoric Southwest. *SFI Studies in the Sciences of Complexity*, Proc. Vol. XVI. Addison-Wesley.

- GUNDERSON, L. H., C. S. HOLLING, AND S. S. LIGHT, EDITORS.
1995 *Barriers and Bridges to the Renewal of Ecosystems and Institutions*. New York: Columbia University Press.
- HAAS, J.
1982 *The Evolution of the Prehistoric State*. New York: Columbia University Press.
- HALL, A. S., EDITOR.
1995 *Maximum Power: The Ideas and Applications of H. T. Odum*. University Press of Colorado.
- HALLPIKE, C. R.
1973 Functionalist Interpretations of Primitive Warfare. *Man* 8(3):451-470.
- HANDWERKER, W. P.
1989 The Origins and Evolution of Culture. *American Anthropologist* 91(2):313-326.
- HARDIN, G.
1993 *Living Within Limits: Ecology, Economics, and Population Taboos*. New York and Oxford: Oxford University Press.
- HARVEY, D. L., AND M. H. REED.
1994 The Evolution of Dissipative Social Systems. *Journal of Social and Evolutionary Systems* 17(4):371-411.
- HARRIS, M.
1977 *Cannibals and Kings: The Origins of Cultures*. New York: Random House.
1979 *Cultural Materialism: The Struggle for a Science of Culture*. New York: Random House.
- HILL, K., AND A. M. HURTADO.
1996 *Ache Life History: The Ecology and Demography of a Foraging People*. New York: Aldine de Gruyter.
- HO, M., AND P. T. SAUNDERS.
1984 "Pluralism and Convergence in Evolutionary Theory," in *Beyond Neo-Darwinism: An Introduction to the New Evolutionary Paradigm*, Edited by Mae-Wan Ho and P. T. Saunders, pp. 3-11. London: Academic Press.
- HOLLING, C. S.
1986 "Resilience of Ecosystems: Local Surprise and Global Change," in *Sustainable Development of the biosphere*. Edited by W. C. Clark and R. E. Munn, pp.292-317. Cambridge: Cambridge University Press.
1993 Investing in Research for Sustainability. *Ecological Applications* 3(4):552-555.
1995 "What Barriers? What Bridges," in *Barriers and Bridges to the Renewal of Ecosystems and Institutions*. Edited by L. H. Gunderson, C. S. Holling, and S. S. Light, pp. 3-34. New York: Columbia University Press.
- IBERALL, A. S.
1985 Outlining Social Physics for Modern Societies—Locating Culture, Economics and Politics: The Enlightenment Reconsidered. *Proc. Natl. Acad. Sci.* 82:5582-5584.

- IBERALL, A. S.
1987 "A Physics for Studies of Civilization," in *Self-Organizing Systems: The Emergence of Order*. Edited by F. E. Yates, A. Garfinkel, D. O. Walter, and G. B. Yates, pp. 521-542. New York and London: Plenum Press.
- JANTSCH, E.
1982 "From Self-Reference to Self-Transcendence: The Evolution of Self-Organization Dynamics," in *Self-Organization and Dissipative Structures: Applications in the Physical and Social Sciences*. Edited by W. C. Schieve and P. M. Allen, pp. 344-353. Austin: University of Texas Press.
- JOHNSON, A. W., AND T. EARLE.
1987 *The Evolution of Human Societies: From Foraging Group to Agrarian State*. Stanford, CA: Stanford University Press.
- JOHNSON, L.
1988 "The Thermodynamic Origin of Ecosystems: A Tale of Broken Symmetry," in *Entropy, Information, and Evolution: New Perspectives on Physical and Biological Evolution*. Edited by B. H. Weber, D. J. Depew, and J. D. Smith, pp. 75-106. Cambridge, MA: MIT Press.
- 1992 An Ecological Approach to Biosystem Thermodynamics. *Biology and Philosophy* 7:35-60.
- KAHLIL, E. L., AND K. E. BOULDING, EDITORS.
1996 *Evolution, Order and Complexity*. London and New York: Routledge.
- KAUFFMAN, S.
1990 *Origins of Order: Self-Organization and Selection in Evolution*. Oxford: Oxford University Press.
- KEEGAN, W. F.
1995 Modeling Dispersal in the Prehistoric West Indies. *World Archaeology* 26(3):400-420.
- KOHLER, T. A.
1992 Prehistoric Human Impact on the Environment in the Upland North American Southwest. *Population and Environment* 13:255-268.
- LANCASTER, J.
1989 The Theory of Radially Evolving Energy. *Intern. J. General Systems* 16:43-73.
- LANSING, S. J.
1991 *Priests and Programmers: Technologies of Power in the Engineered Landscape of Bali*. Princeton, NJ: Princeton University Press.
- LOTKA, A. J.
1925 *Physical Biology*. Baltimore: Williams and Wilkins.
- LOYE, D., AND R. EISLER.
1987 Chaos and Transformation: Implications of Nonequilibrium Theory for Social Science and Society. *Behavioral Science* 32:53-68.
- MARUYAMA, M.
1982 "Four Different Causal Metatypes in Biological and Social Sciences," in *Self-Organization and Dissipative Structures: Applications in the Physical and Social Sciences*. Edited by W. C. Schieve and P. M. Allen, pp. 354-361. Austin: University of Texas Press.

- MISHLER, B. D., AND M. J. DONOGHUE.
1992 "Species Concepts: A Case for Pluralism," in *The Units of Evolution: Essays on the Nature of Species*. Edited by M. Ereshefsky, pp. 121-137. Cambridge, MA: MIT Press.
- MORAN, E. F.
1990 "Level of Analysis and Analytical Level Shifting: Examples from Amazonian Ecosystem Research," in *The Ecosystem Concept in Anthropology* (2nd ed.). Edited by E. F. Moran, pp. 279-308. Boulder, CO: Westview Press.
- MORGAN, L. H.
1877 *Ancient Society*. New York: Holt, Rinehart and Winston.
- NETTING, ROBERT MCC.
1993 *Smallholders, Householders: Farm Families and the Ecology of Intensive, Sustainable Agriculture*. Stanford, CA: Stanford University Press.
- ODUM, H. T.
1983 *Systems Ecology*. New York: John Wiley.
1988 Self-Organization, Transformity, and Information. *Science* 242:1132-1139.
1996a *Environmental Accounting. Emergy and Decision Making*. New York: John Wiley.
1996b Scales of Ecological Engineering. *Ecological Engineering* 6:7-19.
- ODUM, H. T., AND E. P. ODUM.
1997 *A Prosperous Way Down: Principles and Policies*. Niwot, CO: University Press of Colorado.
- ODUM, W. E., E. P. ODUM, AND H. T. ODUM.
1995 Nature's Pulsing Paradigm. *Estuaries* 18(4):547-555.
- ODUM, H. T., AND R. C. PINKERTON.
1955 Time's Speed Regulator: The Optimum Efficiency for Maximum Power Output in Physical and Biological Systems. *American Scientist* 43:321-343.
- O'GRADY, R. T., AND D. R. BROOKS.
1988 "Teleology and Biology," in *Entropy, Information, and Evolution: New Perspectives on Physical and Biological Evolution*. Edited by B. H. Weber, D. J. Depew, and J. D. Smith, pp. 285-316. Cambridge, MA: The MIT Press.
- O'NEILL, R. V., D. L. DEANGELIS, J. B. WAIDE, AND T. F. H. ALLEN.
1986 *A Hierarchical Concept of Ecosystems*. Princeton, NJ: Princeton University Press.
- ORANS, M.
1974 Domesticating the Functional Dragon: An Analysis of Piddocke's Potlatch. *American Anthropologist* 77:312-328.
- ORLOVE, B. S.
1980 Ecological Anthropology. *Annual Reviews of Anthropology* 9:235-73.
- PARK, T. K.
1992 Early Trends Toward Class Stratification: Chaos, Common Property, and Flood Recession Agriculture. *American Anthropologist* 94:90-117.
- PERLIN, J.
1991 *A Forest Journey: The Role of Wood in the Development of Civilization*. Cambridge, MA: Harvard University Press.

- PRIGOGINE, I.
1980 *From Being to Becoming: Time and Complexity in the Physical Sciences*. New York: W.H. Freeman and Company.
- PRIGOGINE, I., AND I. STENGERS.
1984 *Order Out of Chaos: Man's New Dialogue with Nature*. Toronto: Bantam Books.
- RINDOS, D.
1985 Darwinian Selection, Symbolic Variation, and the Evolution of Culture. *Current Anthropology* 26(1):65-88.
1986 The Genetics of Cultural Anthropology: Toward a Genetic Model for the Origin of the Capacity for Culture. *Journal of Anthropological Archaeology* 5:1-38.
- SALTHER, S. N.
1985 *Evolving Hierarchical Systems: Their Structure and Representation*. New York: Columbia University Press.
- SANDERSON, S. K.
1990 *Social Evolutionism: A Critical History*. Cambridge, MA: Blackwell.
- SANDERSON, S. K., EDITOR.
1995 *Civilizations and World Systems: Studying World-Historical Change*. Walnut Creek: AltaMira Press.
- SCHMINK, M., AND C. H. WOOD.
1987 "The "Political Ecology" of Amazonia," in *Lands at Risk in the Third World: Local Level Perspectives*. Edited by P. D. Little, M. M. Horowitz, and A. E. Nyerqes, pp.38-57. Boulder and London: Westview.
- SERVICE, E. R.
1971 *Primitive Social Organization: An Evolutionary Perspective*. New York: Random House.
1975 *Origins of the State and Civilization: The Process of Cultural Evolution*. New York: W.W. Norton and Company.
- SIMBERLOFF, D.
1980 A Succession of Paradigms in Ecology: Essentialism to Materialism and Probabilism. *Synthese* 43:3-39.
- SMITH, E. A.
1984 "Anthropology, Evolutionary Ecology, and the Explanatory Limitations of the Ecosystem Concept," in *The Ecosystem Concept in Anthropology*. Edited by Emilio F. Moran. Boulder, CO: Westview Press.
- SMITH, E. A., AND B. WINTERHALDER.
1992 *Evolutionary Ecology and Human Behavior*. New York: Aldine de Gruyter.
- STEWART, J. H.
1955 *Theory of Culture Change: The Methodology of Multilinear Evolution*. Urbana: University of Illinois Press.
- SOUTH, S.
1990 "From Thermodynamics to a Status Artifact Model: Spanish Santa Elena," in *Columbian Consequences* (Vol. 2). Edited by D. H. Thomas, pp.329-341. Washington and London: Smithsonian Institution Press.

- TAINTER, J.
1988 *The Collapse of Complex Societies*. Cambridge: Cambridge University Press.
- ULANOWICZ, R. E.
1986 *Growth and Development: Ecosystems Phenomenology*. New York: Springer-Verlag.
1996 "The Propensities of Evolving Systems," in *Evolving Order and Complexity*. Edited by E. L. Kahlil and K. E. Boulding. London and New York: Routledge.
- VAYDA, A. P.
1983 Progressive Contextualization: Methods for Research in Human Ecology. *Human Ecology* 11(3):265-281.
1986 Holism and Individualism in Ecological Anthropology. *Reviews in Anthropology* 295-313.
- VAYDA, A. P., AND B. J. McCAY.
1975 New Directions in Ecology and Ecological Anthropology. *Annual Review of Anthropology* 4:293-306.
- WALLERSTEIN, I.
1974 *The Modern World-System I: Capitalist Agriculture and the Origins of the European World-Economy in the Sixteenth Century*. New York: Academic Press.
- WHITE, L. A.
1949 *The Science of Culture*. New York: Grove Press.
1959 *The Evolution of Culture: The Development of Civilization to the Fall of Rome*. New York: McGraw-Hill Book Company.
- WICKEN, J. S.
1987 *Evolution, Thermodynamics, and Information: Extending the Darwinian Program*. New York: Oxford University Press.
- WINTERHALDER, B.
1984 Reconsidering the Ecosystem Concept. *Reviews in Anthropology* 11(4):301-307.
- YOFFEE, N., AND G. L. COWGILL, EDITORS.
1988 *The Collapse of Ancient States and Civilizations*. Tucson: University of Arizona Press.