COEVOLUTIONARY CONTRADICTIONS: PROSPECTS FOR A RESEARCH PROGRAMME ON SOCIAL AND ENVIRONMENTAL CHANGE

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NORGAARD, R. B. and KALLIS, G. (2011): 'Coevolutionary contradictions: prospects for a research programme on social and environmental change', *Geografiska Annaler: Series B, Human Geography* 93 (4): 1–12.

ABSTRACT. Insights from social system–environmental system coevolutionary thought experiments are abstract, mind opening, and can only be conveyed by leading readers through the experiment themselves. Undertaking applied coevolutionary analyses requires one to bound processes and fix some of the categories, contrary to the nature of the broad, opening nature of coevolution itself. Being conscious of these contradictions makes it difficult to engage in a sustained research programme or form a community of coevolutionary scholars. In this article we engage with the epistemological tensions of conducting coevolutionary research and put forward tentative strategies for managing them.

Keywords: coevolution, environmental system, epistemology, social system, socio-environmental coevolution

Evolution, coevolution and mental experiments

This article discusses a coevolutionary approach to the analysis of socio-environmental interactions. Although developed largely outside geography, coevolution is highly relevant for geographers since dynamic interactions between human and environmental systems are at the core of the discipline.

Scholars have undertaken mental experiments with coevolutionary frameworks to explore possible interrelations between social and environmental change for a quarter of a century. We use the term mental experiments deliberately. These refer to engagements with a broadly defined concept, using it to reframe understandings of empirical phenomena. We distinguish experiments from analytical applications which include more or less common terminology and the development of a common set of hypotheses. Quite a few scholars have explored questions through a coevolutionary framework and gained new insights. Some scholars credit coevolutionary mental experiments for opening their minds and broadening their competence. None to our knowledge, however, have fully adopted and developed an applied research programme on the relationships between social and environmental systems using a coevolutionary analytical framework. Empirically well-developed applications do not yet exist. Commonly treated as an episodic or perhaps periodic mental experiment rather than as a framework for ongoing empirical work, coevolution has not brought together and consolidated a research community. Meanwhile controversies continue regarding the use of evolutionary and coevolutionary framings in the social sciences generally including their application to social and environmental change. The combination of mental experimentation, a weak scholarly community, few practical applications, and controversy cloud the status of this mode of explanation, making it both difficult to interpret and difficult to build on. We address this history to better establish the nature of this mode of explanation and its possible future role.

Evolution is a general process of selective retention of renewable variation (Campbell 1969). In coevolution, two evolving systems causally influence the evolution of each other. (Co)evolving populations might include – among others – species, habits, organizations, technologies, ideas (Kallis 2007). Socio-environmental coevolution involves interactions between evolving human (material and ideational) and biophysical systems (Kallis 2007). In a broader sense, coevolution takes place also when an evolving human system transforms a (non-evolving) biophysical system and adapts to its transformations (Norgaard 1994, see also Lewontin and Levins 2007). In a hypothetical spectrum of approaches ranging from mental experiments to analytical applications, the former focus on broad insights from coevolutionary dynamics, such as positive feedbacks, mutual adaptation or path-dependency, whereas the latter focus more specifically on processes that introduce new variation and mechanisms that selectively winnow variation.

Ever since Darwin, scholars have invoked variation and selection to explain social change. The

significance of coevolution arose however only quite recently. Darwin and evolutionary biologists subsequently were well aware that the environment that determined selection in one species was partly, if not largely, determined by the evolution of other species. Surprisingly, however, biologists did not seriously focus on the coevolution of species until a famous empirical documentation by Ehrlich and Raven (1964). Although evolutionary ideas have moved back and forth between social and natural sciences, coevolutionary arguments with respect to social phenomena are quite recent. Durham (1976) appears to have been the first to explicitly argue that human culture and genetic traits coevolve. Many found the explanations for human social behaviour in E. O. Wilson's (1975) sociobiology far too biologically driven, and extensive debate followed about the relative importance of biology and culture. In response, Lumsden and Wilson (1981) and Cavalli-Sforza and Feldman (1981) introduced formal models of genetic and cultural change in which each selected on and thereby affected the distribution of traits of the other. The literature on coevolution between genes and culture in humans has developed fairly systematically with the emphasis on explaining seemingly universal behavioural and social phenomena such as altruism and the rise of common mores and other institutions supporting common behaviour in the collective good (Boyd and Richerson 1985; Durham 1991). Though both the framework and documentation remain controversial, the study of gene–culture coevolution has a consistent core of researchers, well defined conceptual debates, and both formal and empirically-rooted arguments (Gintis 2003; Laland and Brown 2002). In this sense, gene–culture coevolution can be recognized as a "field" that both cuts across and makes claims to bridge disciplines in the natural and social sciences.

A coevolutionary mode of explanation for thinking about change between different dimensions of environmental systems and social systems has not progressed along a similar path as that of the study of gene–culture coevolution. Gene–culture coevolution focuses on simple units of culture evolution and studies them largely in primitive societies; socio-environmental coevolution aims to study instead modern societies and complex cultural systems, such as science, technology or institutions. Furthermore, gene–culture coevolution focuses only on humans, whereas socio-environmental coevolution accounts also for other species and the abiotic environment and their coevolution with culture. This makes socio-environmental coevolution a much more ambitious endeavour. In socio-environmental coevolution we see, at best, loosely coupled scholars working in ecological economics, political ecology, and other hybrid fields that arose with concern over sustainable development. Their works investigate links between natural and social systems and bridge across respective disciplines. Some of these scholars have undertaken mental experiments with coevolutionary arguments, but this is simply one framework among many – population dynamics, hierarchy theory, landscape ecology, environmental economics – used within this weakly coupled community. Folke *et al*. (2005) argue that as the number of scholars studying the linkages between social and ecological spheres has expanded and matured, the linkages have become more strongly recognized and the divisions between social and ecological systems have faded. Thus some scholars are now thinking of components interacting in a single social–ecological system. Whether these scholars see two systems interacting or one seamless system, they frame the interconnections of the parts in a wide variety of ways. In some cases, coevolution is stressed. In other cases, coevolution is quite properly one process of change in a systemic framing that includes other types of dynamics. Either way, coevolution is employed within a larger approach of methodological pluralism (Norgaard 1989). This characterization of the role of coevolutionary thinking as one explanatory approach among many being used by a group of loosely knit scholars is the starting point for our review of the status and prospects of the use of this paradigm to understand social and environmental change.

We initiate our summary by reflecting on our own experiences with a coevolutionary perspective, both to provide one form of empirical content and to expose our own biases. We argue that continued mental experimentation with coevolutionary arguments is a positive sign of its usefulness. We note that the dominant frameworks used by this community are elaborations of historic market and Marxist framings, historic framings extended to include ecological systems. While a variety of new systemic framings are in use, none of these new framings dominate our increasing understanding of social and ecological interconnectedness. We then argue that formally developing and empirically pursuing a coevolutionary framework to explain social and ecological change requires identifying

critical categories, selection processes, and analytical boundaries. These are forms of closure that are inherently at odds with the opening process experienced through mental experiments and with how coevolutionary thinking helps us understand the emergence of new properties, processes, and boundaries. Indeed, we argue that the field of gene–culture coevolution is fairly well developed precisely because it has constructed categories and boundaries around its field that institutionalize such contradictions. We then argue that communicating the complexity of well-developed coevolutionary explanations of social and ecological change is most easily done through using words for proximate concepts in dominant patterns of thinking, but this slows the process of education and growth in the number of scholars able to think in this new way. We identify a series of contradictions that must be "set aside" to apply a coevolutionary framework to explain social and ecological change.

Two personal experiments

Both of us can speak from experience and should do so to provide empirical content to some of our arguments and to identify how our experiences affect our interpretation of the possibilities for the development of an intellectual field of inquiry focusing on social system and ecological system coevolution. Norgaard emphasizes the importance of coevolution as a framework for mental experiments and the difficulties in turning it into an analytical approach. Kallis picks up from there and describes his own quest to develop analytical applications of coevolution.

Norgaard

As an early experimenter with a coevolutionary framing of social and environmental change (Norgaard 1981, 1984a and 1984b), I can attest to the intellectual difficulty of the experiment, the many enlightening insights acquired along the way, and the near impossibility of communicating the wisdom gained. My experiment started in 1979 and effectively ended in 1993 when the manuscript for my book headed to the publisher (Norgaard 1994). My initial insights and inspiration arose in the very practical, though also highly political, setting of participating on a planning team for the Amazon within the government of Brazil. I argued that multiple experiments and "natural" selection made more sense than planning given the failure of planning over the past, the dynamics of the system, and the history of development in Europe and North America (Norgaard 1981). I had hoped to empirically elaborate the Amazon story in greater depth, but my mental experiment kept leading me into a broad coevolutionary rethinking of the conventions girding the "reality" I had thought I understood before, the reality of Western and Westernized minds. Five conventions stood out: atomism (reductionism), mechanism (predictability), universalism (everything, everywhere throughout time will eventually be explained by a limited number of basic scientific laws), objectivism (we can see the world as if it is apart from us and how we think), and monism (our separate ways of seeing the world will eventually fit together). Of course, I could not deconstruct how these particular conventions became embedded in all of history. But I could reread widely with a coevolutionary framing on my mind and see how these conventions underlie the stories we tell ourselves. Seeing the world differently allowed me to link disciplinary literatures as I had never been able to before. Most importantly, I enjoyed tremendous intellectual satisfaction.

I stressed social systems, dividing them into knowledge, organizational, technological, and value systems. This simple, and ironic, "reduction" into categories guided my reading while also ultimately helping me realize the impossibility of fully pursuing these categories in my mental experiment. I explored organizational systems and knowledge systems and how they coevolved quite well over a period of fifteen years, but I was only lightly reading on value systems and technological systems. Addressing the literature on these dimensions more thoroughly would entail a doubling in content and quadrupling in linkages. And the new insights from the new linkages, the effects they had on social organization and knowledge, would encourage me to reread the literatures that I had thought I understood before. I was pretty confident that I could eventually understand the literature on technologies. But I knew that the literature on value systems was enormous, without consensus, and with much of it artificially separated from the development of scientific and organizational knowledge for five centuries. And then there was the small matter of the appropriate units of analysis for coevolution within biological systems, a matter of some debate among biological evolutionists. My own exposition of the coevolutionary process typically lumped the natural

world into "environmental systems", though, as I elaborated examples, what was coevolving became more specific. In short, I found the experiment very exciting, yet spiraling outward with no natural boundaries, cutting across broad swaths of literature, swaths greater than I could cover in depth. Indeed, simply keeping up with the new developments in multiple fields was not possible. Nor could I divide and conquer, farming out parts of the literature to graduate students. The few who were interested in a mind blowing experience rather than grounded and bounded training for their PhD realized that the time required to move into and work effectively within the framework was considerable, the available funding nil. And to combine and keep our coevolutionary gleanings from our reading of separate literatures together, we would have to bind ourselves in intellectual conversation for the rest of our careers.

At times I did try to bound my philosophical curiosity and pursue a particular application in order to give it a stronger empirical base. Most empirical work advances through attracting graduate students who develop analyses within some consciously established conventions for doing a style of research. This, however, did not prove that easy either, partly because of my continued attraction to the broader conceptual implications. I faced a fundamental dilemma. How can a "coevolutionist" who understands how knowledge coevolves with social organization not be wary of consciously establishing analytical conventions, training students to think and participate in research experiments in a particular way, and arguing one has now found truth to scholarly and policy communities?

Coevolution did give me a framework for broadly reading, providing me with a much better understanding of the nature of knowledge and of complex systems. It helped me see how technologies diverged from coevolving around a biophysical environment driven by energy from the sun to coevolving around fossil hydrocarbons.[1] This was not simply a technological transition, but rather a transition that through coevolution became embedded in our knowledge, organizational and even value systems as well.

My long coevolutionary mental experiment affected my whole approach as a scholar. It allowed me to step out of the neoclassical economics paradigm, look back at it with a whole new perspective and helped me distinguish between economic theory and the assumptions of economists as a culture. It also provided several unexpected, in some ways negative or at least limiting, outcomes that have proven especially valuable. First, I personally understand the limits of a single mind and the extent to which I am dependent on trusting the knowledge of others. Second, I also understand the limits of formally communicating internalized wisdom to Western and Westernized scholars who have put their faith in reductionist, deterministic reasoning that can be externalized, that is, described as if it were universally true and would eventually cohere with everything else that was being learned. Third, I understand more intimately that how people think is reinforced by numerous informal and formal institutions designed to further how we think and to translate knowledge into action, the realm of cognitive sociology (Zerubavel 1997). Thinking is not simply reinforced through social pressures of those who practice a dominant way of thinking but also by the "needs" of organizational structures that have coevolved with dominant ways of thinking. These unplanned outcomes inform my current work on how complex systems can only be understood collectively, the difficulties of doing so, and the difficulties of transferring a collective understanding into action by society as a whole. In short, the experience was a fantastic experiment on which I still draw.

Kallis

I was in the midst of my PhD research when browsing through the pages of a research report on social valuation processes (see O'Connor 2000). I encountered the pentagram of coevolution (Figure 1). It resonated deeply with my own concerns and thoughts.

I was researching issues of water resource management, institutions and urban development in my native city, Athens, Greece. I started with an environmentalist's concern for the impacts of large urban dams on the environment, but quickly grew discontent with Malthusian-type arguments of absolute physical–ecological limits and the need to constrain human activity within those limits. Without transforming water resources, human settlements would never have come to be, for good and for bad. And who is to decide which the proper limits are, and at what scale? For this purpose, the mainstream economic model would not do. It has little to say about the uniqueness of contemporary environmental problems since it treated environment and water resources as fully substitutable by other forms of capital, without recognizing limitations to technological progress. Furthermore it could not explain how techno-institutional and environmental

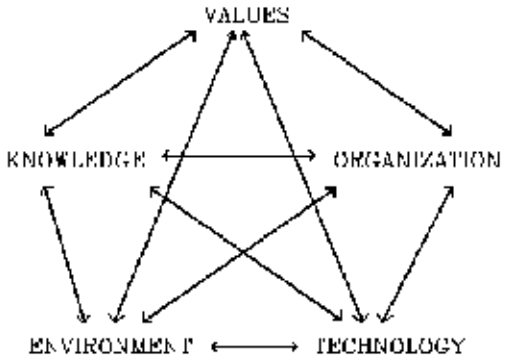

Figure 1. The coevolutionary development process.
Source: Norgaard (1994).

changes take place, other than that they should be efficient.

Norgaard's book gave words to my own quest for moving beyond such environmental vs social determinisms. Coevolution suggested that technologies, values, institutions and knowledge change together. In the process they transform environments, both materially and cognitively, but in turn are transformed by the environments they produce. Crucially, this change is not deterministic. Despite the interlockedness of coevolutionary change, the presence and renewal of variation (diversity), "introductions" from external systems and unpredictable changes, can unsettle evolutionary tracks. This model resonated well with what I was observing in my Athens' case study. The history of the city's water system was a complex, intertwined and contingent process of competing ideas and discourses, visions about the city and actual urban changes, water resource management techniques, institutions and policies, and transformations of the environment.

Applying this coevolutionary perspective would not be easy. I found that there was no coevolutionary application in the literature that could guide my work. Aguilera-Klink *et al*. (2000) in the aforementioned project eventually gave up using coevolution as their methodological framework and opted to focus only on the social construction of water scarcity. The other explicitly coevolutionary applications I found were either histories of societies in the context of environmental changes (Adger 1999), or dynamic system-analyses of positive feedbacks between broadly defined social and ecological variables (Lemon *et al*. 1998; Hadfield and Seaton 1999; Krause and Glaser 2003). None went further than the fairly trivial thesis that society impacts on nature and vice versa.

I looked for inspiration in other literatures. I read works of environmental historians and human geographers, who also attempt to transcend society–nature divides adopting an empirically-rooted historical perspective (e.g., Worster 1985; Gandy 2002; Kaika 2004; Swyngedouw 2004). I was attracted by their ability to connect historical phenomena and empirical data (quantitative and qualitative, environmental and social) with complex philosophical concepts and social theory (e.g., dialectics). This gave me hope for a similar, empirically-rooted coevolutionary approach. From political ecology I also learned to appreciate the importance of power relationships and social inequalities in structuring environmental change and the importance of cultural constructions in framing what we understand as "the environment" or as "the problem". Despite their intentions to address the materiality and agency of nature, however, human geographers in political ecology often tend to emphasize the social over the biophysical (e.g., Castree 2002) and like economists, do not account for the new challenges raised by contemporary environmental change. Furthermore, they often portray a top–down, predetermined causation from "empires" to "colonies" or elites to masses that misses the diversity of interests, struggles and options open in a given historical moment. Perhaps coevolution could provide a better language to talk about interactions between social and biophysical systems, diversity and the contingent, indeterminate dynamics of change.

The novelty of coevolution is not only in "co" but also in "evolution". It is through an evolutionary mode of explanation that agency–structure dualisms and historical determinisms can be transcended. Following the thread from the reviews of van den Bergh and Gowdy (2000, 2003), I found a wealth of theoretical and empirical works analysing economic, institutional and technological change as a (co)evolutionary process (Nelson and Winter 1982; Mokyr 1990; Hodgson 1993; reviews in Nelson 1995 and Nelson and Winter 2002). Searching further, I found a long tradition of evolutionary theorizing in organization science with concrete empirical and policy applications (McKelvey and Aldrich 1983; Aldrich 1999; Bickhard and Campbell 2003) and growing evolutionary applications in political science (Modelski 1996; Hay 1999; Ward 2003). If evolutionary ideas have been meaningfully

applied in these fields, why not in studies of social–environmental change?

Such a project of merging political ecology, environmental history, and evolutionary social science in the spirit of Norgaard's coevolution was too ambitious to be undertaken in my PhD. Through European Union individual research funding, I continued in this line of research and some preliminary results have already been published (Kallis, 2010, Kallis and Norgaard, 2010). I do not dream of *a theory* of socio-environmental coevolution. Instead I aspire to coevolution-based *theories* and diverse, empirically-rich applications similar to those developed by human geographers. I see coevolution as one among multiple alternative perspectives through which we can approach society–environment interactions.

Mental experiments

The rise in coevolutionary thinking during the 1980s coincided with the rise in concern with social and environmental sustainability. Dominant patterns of thinking in the social sciences were thoroughly embedded in institutions fostering Western progress through human mastery of nature, whether through capitalism and markets or socialism and central planning. Thus numerous scholars lit the coevolutionary candle to see what light it casts on the new questions of sustainability. A coevolutionary way of thinking about the past and the future seemed to hold special promise for explaining the human predicament and deriving new policy responses. Institutional ecological economists critical of narrow arguments in favour of markets have found it especially attractive for thinking about social and environmental sustainability (Swaney 1986). Environmental sociologists have also been drawn to its possibilities (Dietz *et al.*1990; Burns and Dietz 2001).

Though a coevolutionary framework stresses how dominance arises and persists rather than power controls, scholars in the Marxist tradition have also been enticed by how a coevolutionary paradigm avoids both environmental and social determinism. Their emphasis on history and familiarity with the "back and forth" of Hegelian explanations make it fairly easy to move to coevolutionary explanations of history. Coevolution helps explain how power evolves, transforms, and sometimes breaks apart without a revolution of the working classes (Woodgate and Redclift 1998). Lippit (2005) used coevolution as a mental experiment to highlight how the economies of the United States, the former Soviet Union, and now China have coevolved around technologies fuelled by fossil hydrocarbons, in spite of significantly different political and economic systems, while also providing a way of enriching the explanation of the dominance of capitalism.

None of these scholars have fully committed their research programme to a coevolutionary framework or developed a consistent terminology and analytical approach. For them, moving from a broad conception of coevolution to a more specific definition of evolving populations and renewal/selection processes may be increasingly more difficult than rewarding. Many scholars addressing social and environmental system change credit their thinking to a coevolutionary framework without demonstrably identifying variation and selection and what is evolving with what (Adger 1999; Lemon *et al.* 1998; Hadfield and Seaton 1999; Krause and Glaser 2003).

The importance of mental experimentation should not be underestimated. First, just as a day in a museum in China helps Westerners put the rise of both science and power in the West in perspective, a little exposure to the coevolutionary framework can quickly highlight the characteristics of dominant ways of thinking today. Second, what other new way of thinking is being pursued more seriously by scholars addressing the interplay between social and environmental systems? Most scholars in this area have opened up and eclectically augmented the market or Marxist framework they used before. Much of ecological economics and political ecology and various blends between them fit this description. Sometimes the broadening, or opening up, is considerable, commonly enhancing methodological eclecticism rather than another framework becoming dominant. A possible exception to this argument has been the cluster of thinking that was brought together and furthered through the Resilience Alliance. Among scholars working in this group, C. S. Holling's adaptive cycle model of four ecosystem functions, the circle twisted into a "figure 8", plays a central role in organizing a variety of conceptual analyses and narratives of ecological and social change (Gunderson and Holling 2002). Even in this case, however, we have an example of a more tightly knit group of scholars engaging in mental experiments that are only weakly appreciated by those beyond the group rather than recognized as an established field like gene–culture coevolution.

There are also good reasons to move back into dominant ways of thinking that we should

acknowledge in assessing the "mere" experimentation with coevolutionary framings of social and environmental change. From the newly acquired perspective, the strengths and weaknesses of the dominant literature look different and new research priorities can emerge. Thus Norgaard was able to see more clearly how the infinitely-lived agent model had become dominant and to work with Howarth on models of overlapping-generations to explain more fully how sustainability is an issue of equity across generations rather than efficiency (Howarth and Norgaard 1995). A more pertinent example, however, is that of Alistair Munro (1997) who explored the broad issues of the evolution of resistance to antibiotics and pesticides through a coevolutionary framework and then answered more specific questions within an optimal control framework.

Contradictions of application

There are important barriers to overcome, in some cases incongruities to be resolved, to apply a coevolutionary framework to explain social and environmental change. Coevolution is the evolution of variation between populations that are systemically related. Thus the systemic nature of the system and its most important relationships need to be defined. It is important to realize that these systemic relationships are themselves dynamic, that is, some changes, perhaps the vast majority of changes in the short run, are comparable to the dynamics between predator and prey in population models in ecology. Yet it is not typically obvious in a world of constant change what is simply change stemming from new conditions and perturbations that are "mechanical" responses of the system and what is coevolutionary change. Indeed, coevolutionary change cannot even be understood as occurring around some mean condition of the system because some mechanical changes have long time lags, certainly long relative to the evolutionary times of microbes, or even insects. Distinguishing coevolutionary change from other types of change, however, is even more complicated than this.

More so than biologists, social scientists see systems hierarchically. Social institutions operate at multiple levels from the local to the global and back. Indeed, many social scientists engage with institutions at different levels and are well aware of the complexity of their interactions. This raises difficult questions concerning the systemic relationships between different hierarchical levels (e.g., between the local and the global, or between agents and structures) that lead to potential asymmetries in coevolutionary interactions. How do we identify the most important systemic relations *a priori?* Indeed, is not identifying the factors underlying the emergence of new important relations the real challenge? In practice, few get beyond the initial task of defining the system and characteristics of coevolving components and hypothesizing how selection takes place, in other words, what are the selection mechanisms.

This is not a problem unique to coevolution of social and environmental systems. Evolutionary biologists are trained to look for the evolution of genetic traits within populations that are typically locally defined. Stephen J. Gould argues that the "modern synthesis" in evolutionary thinking has focused at this level and systematically tried to exclude thinking about evolution at "higher" levels (Gould 2002). Similarly, gene–culture coevolution is broader than sociobiology, but only barely so. Those working in the field of gene–culture coevolution comfortably avoid asking whether culture has units that have systemic dynamics of their own and coevolve among themselves. It avoids questions of natural environment altogether. Opening up the model raises serious questions of focus as well as serious questions of relative importance. In this sense, gene–culture coevolution is probably a minor dynamic in the wider story of social and environmental coevolution (Norgaard 2003). Nor is the problem of defining the system, its appropriate units and selection mechanisms, simply one of added complexity from considering interactions at "higher" levels. The dominant genetic paradigm of the 1980s has become much further complicated by the findings of evolutionary developmental biologists looking at the interactions between genes and their development environment (Gould 2002; Keller 2002).

Thus we are faced with a contradiction. To develop applications of social and environmental coevolution, we need to construct models of key components and key selective pressures. On what basis do we identify what is key both historically and to provide lessons for the future? This is further complicated by the fact that our biological understanding of the evolutionary process is rapidly expanding. Many biologists still portray genes as fundamental building blocks comparable to atoms for physics or chemistry. Yet it is now becoming "clear" that gene expression is affected, and in some cases effected, by developmental conditions (Keller 2002). In the light of more recent linkages

being made between evolution and developmental biology, most applied evolutionary work in biology can be seen as grossly incomplete or even wrong, yet evolutionary biology is still able to build on the insights of earlier work. These advances, and increased complexity, in our biological understanding of evolution mean that there are no "correct" theoretical analogues for thinking about the coevolution of social and environmental systems. Ironically, the grander strength of a coevolutionary way of thinking about social and environmental change is that it helps one see both how the past entailed the convergence of many systemic factors and the emergence of new components, keeping one's mind open to the possibilities of emergence again in the future. No doubt avoiding such complications, putting these contradictions aside, help a field "advance", but just as surely the limitations of the advances will haunt us some day.

Communication challenges

Once immersed in coevolutionary thinking, how does one communicate what one has learned? Clearly, it is challenging to communicate a coevolutionary argument without simply resorting to a "story" that everyone can understand without having gone through the same coevolutionary mental experiment themselves. Indeed, key insights such as how the future depends on how coevolutionary change is rooted to existing components in the systems can be simply summarized as path dependence, positive feedbacks or dialectics. For example, histories of the fossil fuel economy, similar to this of Lippit have been told, without the use of coevolution. Coevolution helps us understand how new properties "emerge", but one can simply assert that new properties do emerge, appealing to some abstract notion of a complex system without having to explain how new things emerge in coevolutionary detail. And the management implications of "emergence" have an existing literature, that is, adaptive environmental management. Similarly, evolutionary ways of thinking help us see the role of diversity in sustainability, but so does the metaphor of not putting all of one's eggs in the same basket. And so it is tempting, indeed to some extent necessary, to draw on commonly understood words, or skip ahead in the argument, so that the details of coevolving systems do not have to be fully spelled out. Two problems result. First, it is difficult to determine to what extent the original researcher actually thought the problem through in some coevolutionary detail. Second, by resorting to shortcuts, those who are trying to communicate coevolutionary arguments are not training a new cadre of readers to actually think through a coevolutionary argument. Either way, the development of this mode of argumentation suffers and becomes open to criticism.

A special challenge of communicating coevolutionary arguments is that the insights they yield are applicable to a world in which coevolutionary thinking has had as much, or more, influence on institutional design as conventional thinking with its embedded assumptions of atomism, mechanism, universalism, monism, and objectivism. Other fields suffer the same problem. Economists have long known that their prescriptions with respect to the efficiency of markets are only true in a world of already efficient markets (Lipsey and Lancaster 1956). Nevertheless, they have developed rationales, reinforced within the culture of economists, for why economic prescriptions apply in the inefficient world we have. Coevolutionary policy prescriptions much more clearly do not fit our existing social structure and processes that have coevolved around dominant assumptions, and there is not a community of scholars pretending as if they do.

Analytical applications

Being aware of such challenges need not hinder development of analytical applications. It does however motivate modesty and consciousness of the limitations of the models we develop. We recognize that a theory, an explanation of an empirical phenomenon or a historical narrative, has to abstract and generalize from an infinitely complex reality. Recognizing a partial contradiction with a coevolutionary epistemology, we still have to reduce and develop simpler stories. This does not contradict the commitment to pluralism and complexity in so far as we recognize that these stories are partial views of reality, not universal models of everything. The pentagram of coevolution is neither a theory of everything nor a model directly applicable to empirical cases. It is a heuristic to remind us that in analysing environmental problems or telling development–environment histories one has to account for the interconnected evolution of material practices, human relationships, knowledge (and its application through technologies), ideas (and their representations) and non-human environments (biological and physical).

The challenge of reduction lies in defining

precisely the variables that coevolve and the selection mechanisms that relate them. There is no patent recipe for how to do that, but there are two principles of good practice: (1) engaging with the empirical material to identify what is relevant to tell a good story; and (2) benefiting from existing systematizations and explanations in the natural and social sciences. For example categories such as genes, populations, institutions, routines, ideological heuristics, types of discourses, technological designs, and so on, can help us build a coevolutionary account. Rather than resolving big questions about the "nature of nature" or society vs nature at an abstract level, we propose a pragmatic approach of engagement with empirical phenomena. We might not be able to demarcate the social from the natural, but we can tell important stories of coevolution of variables along the socio-environmental continuum, such as populations of fish and fishermen or pests and pesticides. And when a sufficient critical mass of such stories is available, then we might be able both to reflect on larger theories of socio-environmental change and their political implications.

Three types of coevolutionary applications, in an order of increasing analytical formality, could be developed. The first refers to more robust mental experiments with empirical backing. We could take coevolution at its most general to refer to an interrelated change of material, ideational and non-human factors, and then let our story speak. Much of existing environmental history is implicitly coevolutionary in this sense (and recently, history more generally; e.g., Mazower 2000). The quality of the account will depend on the breadth of the empirical material brought forward and the documentation of causal propositions. For example, a history of the pesticides problem in the US could involve a documentation of historical interdependent changes in products and agricultural technologies, industries, interest groups and regulations, ideas about nature, discourses and beliefs about the pesticides problem, impacts on the physical environment by pesticide use and changes in the characteristics of pest populations, and so forth. The challenges here are two: (1) how to balance plurality and interconnectedness with causal explanatory accounts; and (2) how not to fall back in either a social or an environmental determinism, paying lip service to coevolution. In other words, the challenge is how to remain coevolutionary without landing in the banal suggestion that everything is related to everything else.

Second, we could use more explicit evolutionary concepts, like variation (and its renewal), selection (or more generally, differential survival) and retention and draw analogies from evolutionary systems (e.g., path dependency, punctuated equilibrium, etc.) as metaphors to frame historical narratives and hypotheses for specific case-studies. Here we will have to become more explicit about what it is that coevolves and how. We will have to identify variants, changes in populations, mechanisms of introduction of new variation and processes of selection. In the pesticides story for example, we might identify a variation of pesticide products, pests, discourses about the problem and institutional options. The goal would then be to show, and to the extent possible document, how the dominance of some variants (e.g., certain discourses about the problem) exerted selective pressure on other variants (e.g., institutional options which in turn selected for certain products in the market which in turn affected the population of pests on the ground). Path-dependency can illuminate how the dominance of certain discourses and institutional options may have locked-in with certain economic and regulatory interests to block transformation to alternative production options. Ideas of introduction, generation of diversity or punctuation can help us track factors that may unsettle this interlocked path. In addition to the challenges of defining systems and interactions, the task here is also how to make a case for the evolutionary dimension, that is, document the presence and differential survival of variants, and go beyond a causal, positive-feedback explanation.

Third, we could try developing more formal models (of the type developed by Nelson and Winter 1982 or Nelson 2002 for economic-technological systems) and test them with data/statistical analyses. Like organization scientists, we might define specific taxonomies of populations of analytical relevance, develop hypotheses about interrelations of population attributes and measure and verify them. For example, we might define a taxonomy for a population of pesticide products in a given geographical area (e.g., given severity of pesticide) and a taxonomy for pest population (given certain characteristics). We might then use a coevolutionary equation from biology to foresee changes and then use existing data sets to test our predictions. We lose something in terms of breadth of analysis (i.e., there are various other factors at play and various variables that mediate the relationship between pesticides and pests) but we gain in formality and clarity of documentation. The challenge here is to find

the data sets that would conform to the requirements raised by our taxonomies.

These three research strategies are not mutually exclusive, but rather complementary. Furthermore, we do not imply that a coevolutionary framing is applicable everywhere nor that it is the only mode of explanation. A collapse of fisheries may best be described in ecology/resilience terms, the dynamics of a river in mechanical terms, and a story of corporate resource loot in an area of a marginalized indigenous population with a political ecological narrative. Developing a coevolutionary approach for its own sake should be avoided. Application should be constrained to cases where – at least intuitively – coevolutionary concepts are relevant. The ultimate test of success is telling a convincing story and relating to a broader pattern (Wilber with Harrison 1978), while bringing new insights in comparison to existing explanations (Nelson 1995). For telling a good story, coevolutionary explanations may well be complemented by other modes of explanation

It should be noted that evolution and coevolution are inherently geographical processes (Thompson 2005). Distance is a barrier that facilitates evolution through isolation. Even if distances are being reduced in modern global social systems, spatial isolation is still important in the emergence and (co) evolution of different socio-environmental paths in different places. Thompson's (2005) metaphor of the 'geographic mosaic of coevolution' is relevant here. The mosaic is a metaphor for the spatial shifts in coevolutionary interaction intensity, as relative abundances and population combinations change in space and time. This is not a static mosaic, but a shifting one producing "banks of entanglement". Human settlements can be thought of as such mosaics of entanglement where different populations of people, artefacts, ideas, animals and plants, are entangled and change together.

A coevolutionary community of scholars and practitioners

We have suggested a variety of directions the development of studies of social and environmental system coevolution might take. If these and other possible directions are pursued, a community of scholars would develop. But this is a chicken-and-egg problem, for it is difficult to encourage others to work in this area without a community of scholars already in place for whom one can write.

Those already thinking about coevolution beyond biology now include scholars working in anthropology (gene–culture coevolution and ethnobiology), economics (ecological, evolutionary, and institutional), environmental history, organizational theory, political ecology and economy, psychology, political science, sociology and geography. More closely tied to biology, we have agroecologists, human ecologists, sociobiologists, and ecologists who now include people in their understanding of systems. This is a rather disparate array of scholars. Except for those working in gene–culture coevolution and evolutionary psychology, most continue to relate primarily to scholars in their broader established disciplines rather than to each other.

The coevolution of social and environmental systems might provide an umbrella under which a broad community could develop. For this to occur, a significant number of scholars would have to take the time to acquire and be comfortable with at least two sets of contradictions. First, there will be contradictions between what their primary discipline or subdiscipline highlight as plausible assumptions and important findings and those of coevolution. Second, working within the coevolutionary framework will never be as "neat and clean" as working within a well established paradigm.

Conclusion

Given the current structure of academe, fields that do not develop through empirical applications are seen as problematic. Introducing a coevolutionary argument into a systemic explanation of social and environmental change has provided a fair number of scholars with a powerful perspective and particular insights. This ought to be sufficient reason for others to continue to experiment with the approach. An approach that does not build into a recognized field is likely to disappear in a scholarly world structured around continual progress in enlightenment. This is especially so for the scholarly world we have today where progress is measured in terms of multiple separate types of expertise and publications rather than a shared enlightenment among scholars.

Note

1. If coevolution does not refer only to two evolving populations but also to a population evolving to an environment it transforms (Lewontin and Levins 2007), then we might argue that human systems coevolved with fossil fuels, transforming them and evolving to their transformations (Norgaard 1994).

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