Sustainability: Science, Practice and Policy

ISSN: (Print) 1548-7733 (Online) Journal homepage: https://www.tandfonline.com/loi/tsus20

Large footprints in a small world: toward a macroeconomics of scale

Lenore Newman & Ann Dale

To cite this article: Lenore Newman & Ann Dale (2009) Large footprints in a small world: toward a macroeconomics of scale, Sustainability: Science, Practice and Policy, 5:1, 9-19, DOI: 10.1080/15487733.2009.11908024

To link to this article: https://doi.org/10.1080/15487733.2009.11908024

Sustainability: Science, Practice, & Policy
http://ejournal.nbii.org

ARTICLE

Large footprints in a small world: toward a macroeconomics of scale

Lenore Newman & Ann Dale

School of Environment and Sustainability, Royal Roads University, 2005 Sooke Road, Victoria, BC V9B 5Y2 Canada (email: lenore.newman@royalroads.ca; ann.dale@royalroads.ca)

The question of scale has been of ongoing interest in the sustainable development discourse, particularly with regard to the size, geographical extent, and complexity of human systems. However, this consideration has not sufficiently informed the practical implementation of sustainable technologies and there remain echoes of historical debates over "small is beautiful" versus "bigger is better" that dominated environmentalism during the 1970s. The complex adaptive nature of social and ecological systems suggests that trying artificially to choose a scale for systems is the wrong approach. A properly managed system should self-organize to a scale that optimizes economic prosperity while respecting ecological limits. For this outcome to occur, however, we argue along the lines of Herman Daly for the effective use of macroeconomic tools. Though the specific form of these tools remains undefined, we draw on complex systems theory to suggest four possible properties based on the concepts of resilience and transformability. These properties are then applied to the food system to demonstrate the self-organization of scale.

KEYWORDS: environmental economics, food consumption, systems analysis, population-environment relationships, ecosystems

Introduction

As human societies continue to grow and expand their resource requirements and waste-sink needs, their impact upon supporting ecosystems is transitioning from negligible and easily accommodated to a level of disturbance that could, and often does, exceed the resilience of the ecosystems involved. This shifting balance is at the root of our environmental challenges and is fundamentally a question of scale. Where once human societies were small enough that they could not disturb the highly resilient ecosystems of the biosphere, human-waste streams and resource needs have now grown to a scale where they can have very broad and long-ranging impacts.

Scale is a critical consideration for sustainable development. As Jordin & Forton (2002) note, "Inseparably alloyed to the scale issue are topological relationships in ecological systems, which require respect for, and maintenance of, their integrity and services. Thus, sustainability is a scale and topology issue–in other words, sustainability must respect the shape and form of the landscape and its prominent features. Despite this critical link, research into scale in the social sciences has been imprecise (Gibson et al. 2000), perhaps due to the historical separation of science and social science in most research institutions. In the environmental context, this question of the "proper" size and scale of human enterprise has largely been framed in terms of the limits to the biosphere's ability to support human society, for example as argued in the *Limits to Growth* report (Meadows et al. 1972). Scale is intuitively integral to sustainable development. Working within a system with fixed limits implies an optimal scale for human systems that is not too small to take advantage of economies of scale, but is not so large as to overwhelm ecological support systems. To ignore such considerations means that the economic system grows unnaturally outside of its productive capacity. Ecological and social systems are multifaceted and exhibit properties of complex adaptive systems such as path dependence, emergent behavior, unpredictability, and unexpected feedback loops (see Newman, 2005 for a more detailed exploration). It is unlikely that an optimal scale could be chosen or anticipated in advance. Sustainable development is a dynamic process and the common approach within the literature of suggesting a "correct" scale is not compatible with the unpredictable nature of complex system dynamics.

This article explores how the concept of scale has evolved within environmental debates, with a focus on Herman Daly's call to develop and use macroeconomic instruments. We look to complex systems theory to suggest some of the properties that these instruments might reflect and conclude by discussing a complex human-ecological system—the food system—in the context of these characteristics. We contend there is a need for better understanding of the factors that contribute to the scale of social systems.

The Concept of Scale

The concept of scale is complicated and variously interpreted by different disciplines. For instance, in ecology one use of the term refers to the relationship between the extent of an activity and the size of its containing environment. In landscape ecology, it is often stated that "scale matters," and certain activities are described as "scale-divergent" meaning that their impact is different depending on the scale at which they are occurring (Schneider, 2001). Political scientists frame scale as an outcome of physical constraints, politics, technology choice, institutional structure, and available information (Lebel et al. 2005). In microeconomics, scale is most often discussed in terms of economies of scale—benefits that are realized by expanding production that, in the case of individual companies, are eventually balanced by diseconomies of scale, and suggest the existence of an optimum size for each organization (Daly, 1992). However, the field of macroeconomics has no real parallel idea, no suggestion that the economy as a whole, or certain subsectors of it, have optimum sizes. Ecological economists such as Herman Daly (1992) vigorously contest this omission, arguing that macroeconomic scale has not been formally recognized and has no corresponding policy instrument. Among geographers, the concept of scale can be confusing, as it has several meanings. The one use germane to the current discussion is phenomenon scale, which refers to the size at which human or physical earth structures or processes exist, regardless of how they are studied or represented (Mason, 2001).

Daly (1991) brought the issue of scale in association with the nature-culture interface to prominence by highlighting the neglected connection between macroeconomics and the environment. He defined environmental macroeconomics as being concerned with flows between the economy and the environment and noted that microeconomics is akin to loading cargo onto a boat and that there is an absolute limit to how much any one boat will carry regardless of how the cargo is arranged. Daly pithily asserted, "Optimally loaded boats will still sink under too much weight even though they may sink optimally." He went on to further claim that this problem needs to be solved using a "non-existent policy instrument." Unfortunately, after the passage of 18 years, no such instrument has emerged into common use, though some interesting possibilities, such as ecological footprinting, have been applied in limited situations at various scales (see, e.g., Wackernagel & Rees, 1994).

The lack of a policy instrument is not an indication that the problem is not severe, but rather highlights the difficulty of addressing complex dynamics. Cumming et al. (2006) discuss the issue of scale mismatches and claim that

> When the scale of environmental variation and the scale of the social organization responsible for management are aligned in such a way that one or more functions of the social-ecological system are disrupted, inefficiencies occur, and/or important components of the system are lost.

An explicit study of scale has not been forthcoming. The issue of scale is also confounded by customary natural resource-management policies that discount cross-level, scale-dependent interactions in favor of the pursuit of maximum yields, a practice that has led to spectacular resource collapses (Young, 2006). Many scale issues evolve over decades, plus most measurements are local and patterns measured locally do not necessarily hold at large scales (Schneider, 2001). The focus on "small is beautiful" among environmental critics has led to the framing of these failures in terms of taking "too much, too fast" from ecosystems, which is certainly a factor, but this framing does not capture the many subtle effects at work. The critical question is: How does scale-dependent interplay affect the sustainability of key biophysical systems, especially those systems that are dominated by human actions? A sustainable scale requires applied knowledge of the spatial-temporal constraints of ecological systems and linkages, knowledge that is still imprecise (Jordan & Fortin, 2002).

Outside of the subgenre of adaptive management, the concept of scale in traditional environmental discourses has lacked the robustness needed to reflect the real qualities of complex adaptive systems. The dominant paradigm that has informed these debates for many years asserts that the scale of interaction should be small wherever possible, though this attitude has diminished in environmental circles, particularly in the era since the 1987 Brundtland Commission. This is not to say that the idea of small-scale endeavors as routes to sustainable development was not revolutionary in its time. Schumacher (1973) argues in his famous book *Small is Beautiful* that we should limit the size of human enterprise relative to nature to reduce the chance of serious harm and this position has been very influential in certain environmental discourses. Some writers like Duane Elgin (1981) particularly target the complexity of our social systems as a problem and others, such as Ted Trainer (1998), take this position to its extreme by calling for self-sufficiency, smallness, decentralization, and extreme simplification. Even those authors who make an honest effort to explore the benefits of small scales are prone to falling into the trap of wishing for a simple society. For example, Papworth (1995) begins his book, evocatively titled *Small is Powerful*, with a reasoned explanation of the benefits of local resource management, but quickly digresses into an argument for the end of cities and markets and a return to a rural, agrarian lifestyle. According to scholars like Morris (1996), "Small is the scale of efficient, dynamic, democratic, and environmentally benign societies," but this emphasis on smallness can also be motivated by wishful thinking for a nostalgic past. More recently, some "peak oil" theorists have recommended a return to small-scale society as a response to the decline in fossil-fuel availability (see, e.g., Kunstler, 2005). At the same time, a dissenting school of thought advocates in favor of large-scale expansion of energy distribution systems (see Newman, 2007). Such continuing polarization leads to the "law of the excluded middle" and marginalizes solutions that transcend dichotomy.

Why has conventional environmentalism focused so intently on the small? It is perhaps a natural human response upon encountering a complex adaptive system to seek simplification to remove complexity and risk. In the past, a single preagricultural human required the Earth to supply a bit under 2,600 kilocalories (kcal) of energy a day, about the same as what a common dolphin requires. In contrast, a single *Homo colossus* [Catton's (1980) term for a contemporary industrial human in the United States] requires the equivalent of a sperm whale's daily supply of more than 202,700 kcal. In times of low population and per capita-resource use, the debate over "small is beautiful" versus "bigger is better" would have been largely an unimportant one as the biosphere dwarfed humanity's impact upon it. This response today, however, is, at best, wishful thinking and, at worst, destructive. Tompkins & Adger (2004) note that adaptation is not about returning to a prior state. Moreover given that we now live in a complex, coevolving socioecological system (Norgaard, 1994), the notion that we could successfully wall off our communities and activities into isolated local enterprises is unlikely, especially given global economic interdependencies with accelerating tendencies to large scale. As Berkes (2006) observes, small-scale systems are rarely free of external drivers, and it is only by accepting the need to engage on many scales that we can successfully respond to challenges in ways critically linked to community resilience.

The other side of the discourse is equally one-dimensional. Critique of the "small is beautiful" concept reached its zenith with the works of the economist Julian Simon (1996). Calling human intelligence the "ultimate resource," he argued that resource replacement and substitution is so easy for us that we will never run out of anything. In the ultimate expression of bigger is better, Simon envisioned exploiting the solar system, and perhaps the galaxy, in an expansion that has no real barriers for hundreds of millions of years. Beckerman (1995) expressed similar, if slightly more nuanced, views in his book, *Small is Stupid*, and suggested that human ingenuity can always work around resource scarcity, but only if we allow economic processes to be as large as possible. Beckerman also relied heavily on the environmental Kuznets curve (EKC), a theory suggesting that as societies develop economically their environmental impact first grows and then falls again after passing a certain per capita-income threshold (see also Grossman & Krueger, 1991). Bigger in this context is not only better, but cleaner. It should be recognized, however, that the EKC does not seem to hold true in many cases, particularly with regard to resource management. Currently, writers such as Lomborg (2001) present the same arguments for "bigger as better" in more polished form. Given the failure of multiple managed resources, particularly with respect to marine resources, it is curious that communities and governments have not more vigorously challenged "bigger is better" policies. However, many elements of society are heavily invested in conventional natural resource use. The popularity of technological fixes, such as carbon capture and storage to control carbon emissions, reflects the belief that, with technological innovation, we can grow our way out of any problem.

There are serious flaws with the neoliberal view charging that Daly's limits are specious given human ingenuity and capacity for technological innovation. At least until the current economic downturn, markets were seen as self-correcting and the main solution of the neoliberal theorist was "less government intervention." However, as Ayres (2007) observes, there is a limit to substitution. For example, light-emitting diodes (LED) convert a very high percentage of energy input into light, so improvement beyond refinement is unlikely. Some things cannot be replaced: "The biosphere embodies a fundamental natural technology for which there is no known alternative and which is truly essential to human survival" (Ayres, 2007). Inventiveness also has limits and there is no guarantee that we can innovate rapidly enough in a world where human systems approach the scale of the natural systems in which they are embedded (Bretschger, 2005; Newman et al. 2008). If exponential growth were to continue, we would need a corresponding exponential rise in innovation.

Though bigger might not be better, throughout history this strategy has proven very effective at reducing the diversity of smaller enterprises. Oram & Doane (2007) aptly note, “The small rarely survives in a world where narrowly defined measures of economic efficiency are the only determinants of success.” Moreover, institutional rigidities and incentives that support the large at the expense of the small worsen the problem. In many of the case-study communities we have investigated, local enterprise is largely extinct. The mismanagement of scale-dependent environmental resource regimes demonstrates that a focus exclusively on one scale at the expense of allowing maximal, rather than optimal, scales to emerge obliterates opportunities for critical feedback and information (Young, 2006). If bigger is not better, and small is not beautiful, what is the optimum scale for social-ecological interactions?

Asking a Different Question

We must address the nature of the needed policy instruments to improve our understanding of the dilemma of scale. This article suggests four aspects of complex adaptive systems that theorists and practitioners should consider in any policy instrument designed to reconcile the scale of societal impacts and the scale of the biosphere. There are likely other important aspects, and, in a few cases, not all four will be relevant. However, our experience with the practical application of various sustainable development technologies and action plans has been that these aspects reappear in almost all cases (see, e.g., Dale et al. 2009).

The nested and interconnected set of scales operating within a system of social-ecological interaction should ideally optimize two qualities critical to sustainable development: resilience and transformability. Holling & Gunderson (2002) define resilience as the magnitude of disturbance that can be absorbed before a structural change occurs. While a system should be able to maintain a degree of stability in the face of surrounding change, sometimes system change is required for long-term sustainability. This capability is known as transformability, the ability to totally alter subsystems if needed (Walker et al. 2004). We also note that, as with many properties of complex adaptive systems, these classifications are necessarily “blurry” and there is certainly some degree of crossover.

The four conditions are as follows:

1. All required independent variables must be considered or integrated into decision making.
2. Communities must employ adaptive comanagement at all subscales to allow local feedback to work its way up through the system.
3. A diversity of options must be available.
4. Processes to prevent lock-in must be in place.

Considering All Required Variables

For any system to be optimally scaled within a surrounding environment, multiple variables must be considered. In short, “how we think about scale depends on what we think is important” (Norgaard, 1994). This observation is abundantly clear with respect to resource management. If, as is often the case, only short-term economic interests are considered, overexploitation of the resource quickly follows. Within the “bigger is better” world of neoliberal economics, the relegation of certain variables, such as harmful emissions, to the category of “externalities” that are not considered in economic calculations removes crucial feedback and allows the scale of our activities to become too large. Sustainable development cannot rely on the notion of optimal solutions based upon a single measurement (Rammel & Van Den Bergh, 2003). The traditional emphasis on maximum yields in natural resource-management policies has led to astounding ecological collapses in fisheries and forests. Kai Lee (1993) attributes this problem of overexploitation to a mismatch of scales and notes that, “When human responsibility does not match the spatial, temporal, or functional scale of natural phenomena, unsustainable use of resources is likely, and it will persist until the mismatch of scales is cured.”

If evaluating all variables related to economic, ecological, and social sustainability would lead to optimal scale, why are so many social-environmental interactions evaluated on only a few variables, or often only on variables associated with economic growth alone? Traditional planning has involved isolating variables of interest, but this approach has decreased resilience (Gunderson, 2000). Though a lack of understanding of environmental impacts and simple expediency both play roles, the delayed nature of our impacts on environmental systems also causes problems. It often requires the passage of years before we come to understand the impacts of our actions. Unfortunately, economists have trouble with slow-moving variables and delayed feedback and tend to focus on fixing issues in the short term (Holling et al. 2002). Diamond (2005) calls this the problem of creeping normalcy—unless we are paying close attention to ecosystems, we can fail to notice system changes that occur over long periods. It is likely that we not only have to observe all relevant social, ecological, and economic variables, but we must do so over a long enough time.

Within the consideration of all variables, there is a normative aspect regarding what goals a society considers at a particular time and who considers them. By favoring some variables over others, we can distinguish between the maximum sustainable scale and the optimal sustainable scale (Lawn, 2001). The optimum scale respects variables necessary for allowing us to meet our social desires, reconciling those with ecological and economic imperatives (Dale, 2001). The amount of free time deemed necessary, for example, might delineate a difference between the optimal and maximal scales.

Implementing Adaptive Comanagement

If we are to respect all relevant variables within a system, we must create institutions that are open and capable of responding to environmental feedback. One of the problems with our customary views of scale is that within complex adaptive systems we do not decouple activities occurring on different scales. A system is not simply large or small, but rather contains nested scales from the overall largest down to local subscales. This structure is central to the resilience of complex adaptive systems, *provided the various scales talk to each other*. Social systems and ecosystems require flexible governance and the ability to respond to environmental feedback (Olsson et al. 2004), and often the feedback arrives at a different scale than the one at which action must be taken. Comanagement across scales is thus critical to solving complex problems (Cash et al. 2006). Some scholars have identified the problem of "fit" between institutions and scale of analysis as a condition for sustainable development that requires working at multiple scales and cross-scale analysis (see, e.g., Folke et al. 2007). As Kastenhofer & Rammel (2005) note, sustainable development is a process of compromise requiring a balance between long-term efficiency and resilience.

Adaptive comanagement of ecosystems that considers both local actors and larger level effects is critical to the creation of resilience and transformability. Use of local ecological knowledge builds resilience as local solutions become tailored to local conditions in ways necessary for healthy ecosystem interactions (Berkes et al. 2000). If many variables are monitored, changes will first be observed "on the ground" locally. Without local involvement, management tends to shift towards exploitation. As local resources are depleted, new resources are substituted in other locations. Focus on a single scale tends to emphasize processes at that scale and to oversimplify the system, sometimes ignoring critical variables (Willbank & Kates, 1999). Gunderson & Holling (2002) capture the complexity of our systems across scales with their term "panarchy," which refers to a set of dynamic systems nested across scales. While governments have yet to usefully define and implement this concept, only by addressing all levels within the panarchy can we get a full understanding of the system and its limits.

The need for local knowledge and observation is not, however, an argument in favor of moving to locally isolated small-scale enterprises. As even local action can have global consequences, resilience emerges from both cross-scale and within-scale interactions (Peterson, 2000). Transformability in the face of external changes requires an outward focus to the larger scale. Connectivity allows resilience and movement, but the existence of local network structure buffers against cascades of disaster from the larger world (Andersson, 2006). That said, for adaptive comanagement to work effectively, it must be collaborative, as without a shared sense of purpose stakeholders at different scales are likely to have very distinct interests. In most cases, global stakeholders are likely to value short-term financial gain over local ecosystem integrity, but, in other cases, local actors might value short-term employment prospects over larger ecological needs. Actors at all scales must work in concert, not at cross purposes.

Creating a Diversity of Options

Ecosystems are divergent under small changes in environmental variables. In other words, if the same species colonizes two slightly different ecological niches, it will then adapt differently in the two places. This is a common resilience-building strategy within complex adaptive systems, making the standardization desired by global economic interests quite puzzling. Ritzer (1996) notes the huge inefficiencies involved in standardization and describes how the savings are often short-term and local. He gives the example of "just-in-time" manufacturing, which saves individual companies money, but clogs the roads with nearly empty trucks.

With diversity comes strength through the preservation of options. Rammel (2003) notes that the preservation of diverse approaches within an economy does not always generate optimal short-term returns, but such a strategy does provide long-term flexibility. Other authors have additionally noticed the lack of diversity in our economy. For instance, Araujo & Harrison (2002) argue that to preserve our agency to act, it is best to hedge bets and maintaining diversity can serve as a useful way to minimize risk (see also Rammel & Van Den Bergh, 2003). Diversity is fundamentally connected to local resilience in a community's ability to respond and adapt in an appropriate time to exogenous variables. In addition, innovation requires accurate price signals and research-friendly environments (Bretschger, 2005).

Intellectual and technical advances will only occur in a robust culture of research, which builds resilience by creating an array of options.

Diversity can be preserved within social-environmental interactions through the encouragement of niche exploitation and "niche accumulation": the adoption of new technologies within specific sets of environments or circumstances in which they enjoy an advantage, allowing them to spread to similar niches. Technical niches protect new technologies from premature rejection (Raven, 2007). Whether experimental niches are available within a society depends on the attitude of the relevant power brokers. Government can encourage niche exploitation or can use regulation to make niche exploitation all but impossible (Rammel, 2003). "Testing" a technology or procedure in a few small niches can help overcome obstacles and, as Raven (2007) points out, this process can lead to "niche branching" in which the technology spreads to a larger, less specialized niche. Kemp et al. (1998) see this as central to the quest for sustainable processes and argue that sustainable technologies will look slightly different in each specific place of application.

Each local context provides a variety of niches for innovation and experimentation. Such spaces are compared to ecological "edge spaces" and function as zones for social interaction, cross-fertilization, and synergy as they increase resilience and are purposely created in some communities. Examples vary from the creation of public space, such as the new city square in Rockville, Maryland, to special zoning to encourage innovation, such as the conversion of manufacturing districts into a public market and space for artists on Granville Island in Vancouver, British Columbia (Rockville, 2007; Granville Island, 2009).

Niche space can also be created by circumstance. Unruh (2002) demonstrates how niche exploitation can encourage a new technology using the example of Edison's electrification of the lighting on the steamship SS Columbia in 1880. Because gas and oil lighting were very dangerous aboard ship, there was an increased openness to experimentation. Such niches can act as a demonstration case for new ideas and technologies. The standardization found in the large-scale corporate model can constrain niche availability, reducing diversity and limiting niche technologies. At best, we passively exploit diversity within our societies to test new processes and technologies (see, e.g., Newman et al. 2008).

Preventing and Correcting Lock-in

If all system variables are under consideration and a signal propagates through a system suggesting a change is needed, it is not assured that the needed change will be possible. Technologies, ideas, and behavior patterns can become entrenched and intertwined, creating a problem known in the literature as "lock-in." Scheffer & Westley (2007) describe lock-in as "ubiquitous" despite the fact that it prevents adjustment to new situations. Diamond (2005) calls this reluctance to abandon what we have even if it does not work the "sunk cost effect" and attributes it to the fact that we have already invested time, energy, and resources in an inferior alternative. Lock-in arises naturally out of two properties of complex systems: path dependence and increasing returns. Technologies and procedures coevolve and so certain system elements take up the role that keystone species play in ecosystems. One cannot simply change them without setting off cascading changes throughout the system.

Path dependence can be described as "reactive sequences" in which each event is precipitated by previous self-reinforcing sequences (Mahoney, 2000). In short, history matters, and a random event can ensure that a suboptimal technology or process becomes the norm. Rammel (2003) points out that sometimes rather mediocre solutions dominate a natural selection process in the short term and that systems—particularly ones of great complexity—can prove very inflexible. Arthur (1994) calls this reenforcement of certain historical paths nonergodic behavior and path dependence matters deeply in his analysis. Although this problem could be minimized by careful use of precautionary principles at the beginning of the development of a technological path, negatives of new technologies often appear after implementation and policies frequently have unintended consequences. The use of chlorofluorocarbons are an example of the significant lock-in of a technology occurring prior to a substantive danger becoming apparent. Identifying a problem and choosing a solution are difficult, but often, as Homer-Dixon (2000) notes, implementation of a solution is the true dilema. Lock-in is a huge problem caused by the increasing returns to mass adoption inherent in many technologies (Carrillo-Hermosilla, 2006).

Recognition of this problem is not new. In his work on the need to shift away from fossil fuels, Unruh (2000) calls lock-in a technological "cul de sac," at its worst cumulating in an embedded technoinstitutional complex that entails the interdependence of a great number of practices and technologies. Society must tackle path dependence and lock-in, but as Unruh (2002) notes "the question of how to overcome large scale lock-ins has been little explored." Unruh (2002) has related lock-in to a lack of diversity (discussed above as condition three) and the encouragement of niche markets is a possible way of breaking lock-in. However, research has shown that in extremely locked-in systems, investigation of options falls to near zero, probably reducing innovation (Redding, 2002). As Arthur (1994) notes, there is a minimum cost for a transition and changing by fiat is sometimes necessary. Correcting lock-in is a critical component of adaptive comanagement, but few successful examples of this process are available.

Scale and the Food System

To illustrate how the four aspects of complex adaptive systems discussed above play out in a real system, we examine how each manifests itself with respect to the production and consumption of food. The transfer of food from ecosystem to table is one of the largest and most important social-environmental interactions. As food production can occur on scales from the microlevel of a backyard-garden plot, to the macrolevel where a single monoculture farm can spread to the horizon, to international institutions that facilitate global exchange, the food system provides an example of how the four conditions influence the self-organization of scale. The food system has overwhelmingly moved to the largest possible scale with the advent of "monster" farms fed by petroleum and supply chains that span the globe. However, a robust countermovement for organic and local food also exists, highlighting the tension between bigger is better and small is beautiful. The four variables are discussed in turn below.

Considering All Required Variables

Food chains are a revealing example of systems where diverse considerations come into effect, as optimal food systems involve many variables. Currently, the primary variables considered by producers and distributors are cost of food and stability of the food supply, but other variables of interest include ecosystem health, food safety, human-health benefits, security of the overall system, social justice for workers, and, of course, taste. Furthermore, climate change has augmented concern for embedded transportation costs. The current industrial food system has relied on plentiful fossil fuels and huge government subsidies to provide what is arguably the cheapest food in history, and one could argue that the food supply has never been so reliable, in the short term at least, for so many people. Given this reality, it is not surprising that local-scale food production has been all but obliterated in many parts of the world. Perhaps the surprise is that an alternative food system comprising local production and a growing network of organic producers that addresses food's forgotten variables has managed to survive at all. That large-scale industrial agriculture damages the environment is hard to argue. Eldredge (1998) calls loss of topsoil one of the most serious hazards facing humanity and Shiva (2000) sees soil loss as a threat to cultures and communities around the world. Some consumers are willing to pay a premium for organic food, in part because organic growers agree to protect their farmland (Delind, 2006). Organic and local foods are also seen as safer, a perception driven by food scares within the industrial system (Vindigni et al. 2002). Ongoing breakdowns in the security of the food system, such as bovine spongiform encephalopathy (BSE) and E. coli outbreaks, have fueled this perception. Local production is also thought to produce fresher and tastier food (as varieties do not have to be chosen for durability over long distances), and regional development and local economic benefit (as local farm economies are preserved) (Nichol, 2003). Delind (2006) echoes these advantages, arguing local food boosts proximate rural economies, is healthier and better tasting, reduces energy needs, and fosters a sense of place. Growers and market organizers often highlight flavor and variety, and proponents often link the preservation of biodiversity with the consumption of local cultivars, which has also emerged as a strong social-justice issue (e.g., Shiva, 2000). A food system that considers all of these variables will, in the long run, be more resilient than an industrial system based on soil exploitation and the existence of cheap fossil fuels.

Adaptive Comanagement Is In Use

Though the industrial food chain deploys little in the way of adaptive comanagement, several sub-streams within alternative agriculture follow the basic tenets of adaptive comanagement. One such concept is permaculture as developed by Mollison & Holmgren (1978). Initially focused on "permanent agriculture" that needs no outside fertilizers and is self-seeding, the concept has expanded to embrace the creation of sustainable human-living spaces in which edible ecosystems are designed to resemble their wild counterparts. Permaculture is about recognizing webs, such as the interaction between the sun, plants, pollinators, fungi, and other elements of an ecological system.

Local food markets also serve an overlooked educational and social purpose introducing new foods into people's diets and highlighting cooking methods, which is especially important given the importance of scale to food quality and nutrient density. Surveys in the Niagara rural region of Ontario, Canada found that farmers' market customers enjoy the chance to interact socially with others interested in local food and with the producers themselves (Feagan et al. 2004). Local foods lack many of the hidden costs of industrial agriculture and shorten the distance between grower and consumer. In contrast, a largely globalized food system has embedded transportation costs and the nutrient value of food sources decreases when transported over long distances.

A Diversity of Options Is Encouraged

Industrial agriculture discourages diversity, increasingly putting all of our metaphorical (and literal) eggs in one genetic basket. This focus on uniformity has led to the widespread destruction of landraces, the variations of major crops adapted to local environments grown by small-scale farmers. As an example, of the 7,000 apple varieties once grown in the United States, 6,000 are now extinct (Shiva, 2000), a phenomenon matched by the destruction of wild relatives to major crops (Douthwaite, 1996). Losing these pools of genetic diversity exposes us to the threat of massive losses due to disease or environmental changes. For instance, if thousands of wild varieties of potato had not been growing in South America at the time of the Irish potato famine, potatoes would likely not be a viable crop today (Douthwaite, 1996). The loss of landrace diversity has exceeded fifty percent for some key crops (see, e.g., Huynen et al. 2004). Large-scale agriculture focuses on output, not diversity. Shiva (2004) highlights the impact of this loss on local farmers who are forced to turn to high-yield varieties and must then buy pesticides and fertilizers to produce the exotic imports that local varieties simply did not need. Across the developing world, this cycle is having the same effect that it did in the developed world, notably the rapid disappearance of the local farmer.

The news, however, is not all bad. For example, the Italian gastronomic activist Carlo Petrini founded in 1989 what has come to be known as the Slow Food movement with the preservation of biodiversity as one of its key goals (Pietrykowski, 2004). Advocates argue for the conservation of local varieties and flavors that contribute to a “rhetoric of terroir” (Miele & Murdoch, 2002). The best nonliteral English transition of terroir might be “distinctness of place,” the quality of a locale that makes it unique. The Slow Food movement seeks to position food as a key constituent in the development and maintenance of community (Pietrykowski, 2004). Others argue for a broader locality theme, claiming that complete neighborhoods are those that meet daily needs locally (Leyden, 2003). Though initially a European trend, local food has become popular in North America as well, particularly after the publication of the “100 Mile Diet” that strongly encourages local production as a way of achieving environmental and health benefits and as a building block of sustainable communities (Smith & MacKinnon, 2007).

Lock-In Is Prevented and Corrected

For the small niches occupied by local and organic food to expand, an overwhelming lock-in of the industrial food system must be overcome. The prospects are not entirely promising. The ability to change our food system is highly limited by lock-in with respect to our social infrastructure (Seyfang, 2007), but more importantly by market infrastructure favoring the large scale. This infrastructure includes massive subsidies for large producers, regulations that inhibit local production and processing of food, and the ever-present effect of cheap and abundant fossil fuel that allows the industrial production and distribution system to function. In the face of this challenge, alternative food systems are thriving in many small niches, in part due to education around the risks created by the industrial system. Knowledge of food production is still limited (Dillon et al. 2005), but these niches will likely continue to grow as more people become interested in their food and as fuel prices rise. Such circumstances make it possible to overcome the problems of lock-in.

The Future of Food

To summarize, the industrial food system demonstrates very clearly the results of failing to take into account the four system requirements of resilience and transformability outlined in this article. However, niche-food systems are developing that focus on local and organic food, and these alternatives are at least beginning to address the four requirements. As expected, the emerging alternative food systems are neither monolithically large nor uniformly small. The exchange of information between regions is a key component of the Slow Food movement as it is meant to be a global transformation, not a scattering of isolated projects. In addition, local food can benefit from embracing some of the economies of scale found in the industrial food system. For instance, studies show that if food production occurs at an overly small scale, energy needs can exceed those of industrial agriculture (Wallgren, 2006; Van Hauwermeiren et al. 2007) as individual farmers drive very small crops to market in fuel inefficient vehicles. This obstacle can be overcome by embedding small producers within a slightly larger distribution system. The role of supply-chain length is also variable. Certain foods that are too delicate to transport, such as specific mushrooms, are produced locally even by large corporations or they are excluded from industrial agriculture entirely. On the other hand, Van Hauwermeiren et al. (2007) found that in many cases growing local crops in greenhouses during winter months was less energy efficient than importing the same crop.

A very interesting example that highlights the nuances of the issue is a study by Sundkvist at al. (2001) that analyzes the potential for local bread production on the island of Gotland in Sweden. They found that on a per kilogram basis the bread produced locally is currently more energy intensive, though it was less greenhouse-gas intensive given the existence of shorter supply chains. However, the authors noted that this energy intensity was a result of external factors such as the unavailability of local flour and the inefficiency of the equipment used on the island. They note that

> The region has a large potential to produce enough flour for its local population and thus to become less dependent on imports. However, using more locally produced bread grain to produce flour in local mills, improving energy efficiency in small-scale mills and bakeries, changing consumer behavior and internalizing environmental costs of transportation are crucial measures in achieving this goal.

Sundvist et al. (2001) also suggest that if local sources of renewable energy were available it would offset the higher energy needs of medium-sized bakery facilities, and they observe that local flour is more nutrient rich and less environmentally harmful than industrial flours. In short, bread produced at the large scale is not the same as bread produced at the small scale, even though the market often treats the two products as equivalent. It is apparent that further studies are needed to develop a more complete analysis of the optimal extent of local production.

Conclusion

We argue that the scale of any particular social-ecological interaction is a complex quality that should evolve as an emergent property of the system's feedbacks and expectations. We agree with Herman Daly that a macroeconomic policy instrument (or suite of instruments) is needed to guide the relationship between social and ecological scales and we suggest that such an instrument must be grounded in complex adaptive systems theory, as both social systems and the biosphere are dynamically interconnected, complex, and adaptive. We suggest four qualities of such systems that we contend could provide a basis for policy-relevant instruments: that all needed variables must be considered, adaptive co-management must be present to incorporate feedback at different scales, a diversity of responses must be available, and lock-in must be corrected and avoided. Although these four aspects are not universal and are not exclusive, they are crucial. One could consider the first two aspects as requirements of resilience and the second two aspects as requirements of transformability. Moving forward, it is critical that we improve our understanding of the requirements of transformability, particularly the ability to correct and prevent the economic, social, and institutional lock-in that emerges within path-dependent processes.

The complex nature of social and ecological systems does pose a challenge to understanding the four aspects. Certainly identifying all of the variables within a system with sensitive dependence on initial conditions and emergent behavior is difficult. Likewise, a precautionary approach within a complex system will be at best only partially successful. These obstacles can be mitigated by using a series of iterative evaluation processes. For example, important variables may become apparent over longer periods. Controlling technological and social lock-in might best be achieved by innovative public policy to support niche markets through government subsidies. It is much easier to shift to another path when the alternative does not have to be invented from scratch. Unfortunately, the current subsidies that most countries provide to incumbent systems enforce rather than challenge homogenous markets. In addition, the funding of research and innovation of all types could improve the diversity of options available.

The above consideration of scale is more than an academic exercise. The tendency to ignore the four factors discussed above, coupled with our high population and per capita-resource requirements, has led to the proliferation of activities totally out of proportion to the resource bases upon which they rely. It is critical that we address this mismatch if we are to repair the integrity of impaired social and ecological systems.

Acknowledgement

The authors wish to acknowledge funding from the Canada Research Chairs Program and the Social Sciences and Humanities Research Council that made this research possible.

References

Andersson, E. 2006. Urban landscapes and sustainable cities. *Ecology and Society* 11(1):34.

Araujo, L. & Harrison, D. 2002. Path dependence, agency, and technical evolution. *Technology Analysis and Strategic Management* 14(1):5–19.

Arthur, B. 1994. *Increasing Returns and Path Dependence in the Economy.* Ann Arbor: University of Michigan Press.

Ayres, R. 2007. On the practical limits to substitution. *Ecological Economics* 61(1):115–128.

Beckerman, W. 1995. *Small is Stupid: Blowing the Whistle on the Greens*. London: Duckworth.

Berkes, F. 2006. From community-based resource management to complex systems. *Ecology and Society* 11(1):45.

Berkes, F., Colding, J., & Folkes, C. 2000. Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications* 10(5):1251–1262.

Bretscheger, L. 2005. Economics of technological change and the natural environment: how effective are innovations as a remedy for resource scarcity? *Ecological Economics* 54(2–3):148–163.

Carrillo-Hermosilla, J. 2006. A policy approach to the environmental impacts of technological lock-in. *Ecological Economics* 58(4):717–742.

Cash, D., Adger, W., Berkes, F., Garden, P., Lebel, L., Olsson, P., Pritchard, L., & Young, O. 2006. Scale and cross-scale dynamics: governance and information in a multilevel world. *Ecology and Society* 11(2):8.

Catton, W. 1980. *Overshoot: The Ecological Basis of Revolutionary Change*. Champaign: University of Illinois Press.

Cumming, G., Cumming, D., & Redman, C. 2006. Scale mismatches in social-ecological systems: causes, consequences, and solutions. *Ecology and Society* 11(1):14.

Dale, A. 2001. *At the Edge: Sustainable Development for the 21st Century*. Vancouver: UBC Press.

Dale, A., Ling, C. & Newman, L. 2008. Does place matter: sustainable community development in three Canadian communities. *Ethics, Place, & Environment* 11(3):267–281.

Daly, H. 1991. Towards an environmental macroeconomics. *Land Economics* 67(2):255–259.

Daly, H. 1992. Allocation, distribution, and scale: towards an economics that is efficient, just, and sustainable. *Ecological Economics* 6(3):185–193.

Delind, L. 2006. Of bodies, place, and culture: resituating local food. *Journal of Agricultural & Environmental Ethics* 19(1): 21–146.

Diamond, J. 2005. *Collapse: How Societies Choose to Fail or Succeed*. New York: Viking Press.

Dillon, J., Rickinson, M., Sanders, D., & Teamey, K. 2005. On food, farming, and land management: towards a research agenda to reconnect urban and rural lives. *International Journal of Science Education* 27(11):1359–1374.

Douthwaite, R. 1996. *Short Circuit: Strengthening Local Economies for Security in an Unstable World*. Dublin: Lilliput Press.

Eldredge, N. 1998. *Life in the Balance: Humanity and the Biodiversity Crisis.* Princeton, NJ: Princeton University Press.

Elgin, D. 1981. *Voluntary Simplicity: Towards a Way of Life That is Outwardly Simple, Inwardly Rich*. New York: William Morrow.

Feagan, R., Morris, D., & Krug, K. 2004. Niagara region farmers' markets: local food systems and sustainability considerations. *Local Environment* 9(3):235–254.

Folke, C., Berkes, F., Colding, J., & Svedin, U. 2007. The problem of fit between ecosystems and institutions: ten years later. *Ecology and Society* 12(1):30.

Gibson, C., Ostrom, E., & Ahn, T. 2000. The concept of scale and the human dimensions of global change: a survey. *Ecological Economics* 32(2):217–239.

Granville Island. 2009. An Urban Oasis. http://www.granvilleisland.com/en/island_info. March 4, 2009.

Grossman, G. & Krueger, A. 1991. *Environmental Impacts of a North American Free Trade Agreement*. NBER Working Paper No. W3914. Cambridge, MA: National Bureau of Economic Research.

Gunderson, L. 2000. Ecological resilience: in theory and application. *Annual Review of Ecological Systems* 31(3):425–439.

Gunderson, L. & C. Holling (Eds.). 2002. *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington, DC: Island Press.

Holling, C. & Gunderson, L. 2002. Resilience and adaptive cycles. In L. Gunderson & C. Holling (Eds.), *Panarchy: Understanding Transformations in Human and Natural Systems*. pp. 25–62. Washington, DC: Island Press.

Holling, C., Gunderson, L., & Ludwig, D. 2002. In quest of a theory of adaptive change. In L. Gunderson & C. Holling (Eds.), *Panarchy: Understanding Transformations in Human and Natural Systems*. pp. 3–24. Washington, DC: Island Press.

Homer-Dixon, T. 2000. *The Ingenuity Gap*. New York: Knopf.

Jordan, G. & Fortin, M. 2002. Scale and topology in the ecological economics sustainability paradigm. *Ecological Economics* 41(2):361–366.

Kastenhofer, K. & Rammel, C. 2005 Obstacles to and potentials of the societal implementation of sustainable development: a comparative analysis of two case studies. *Sustainability: Science, Practice, & Policy* 1(2):5–13.

Kemp, R., Schot, J., & Hoogma, R. 1998. Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. *Technology Analysis and Strategic Management* 10(2):175–196.

Kunstler, J. 2006. *The Long Emergency: Surviving the End of Oil, Climate Change, and Other Converging Catastrophes of the 21st Century*. New York: Grove Press.

Lawn, P. 2001. Scale, prices, and biophysical assessments *Ecological Economics* 38(3):369–382.

Lebel, L., Garden, P., & Imamura, M. 2005. The politics of scale, position, and place in the governance of water resources in the Mekong region. *Ecology and Society* 10(2):18.

Lee, K. 1993. Greed, scale mismatch, and learning. *Ecological Applications* 3(4):560–564.

Leyden, K. 2003. Social capital and the built environment: the importance of walkable neighbourhoods. *Research & Practice* 93(9):1546–1551.

Lomborg, B. 2001. *The Skeptical Environmentalist: Measuring the Real Sense of the World*. New York: Cambridge University Press.

Mahoney, J. 2000. Path dependence in historical sociology. *Theory & Society* 29(4):507–548.

Mason, A. 2001. Scale in geography. In N. Smelser & P. Baltes (Eds.), *International Encyclopedia of the Social and Behavioral Sciences*. pp. 13501–13504. New York: Elsevier.

Meadows, D., Meadows, D., Randers, J., & Behrens, W. 1972. *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind*. New York: Universe Books.

Miele, M. & Murdoch, J. 2002. The practical aesthetics of traditional cuisines: slow food in Tuscany. *Sociologica Ruralis* 42(4):312–319.

Mollison, B. & Holmgren, D. 1978. *Permaculture One*. Melbourne: Transworld.

Morris, D. 1996. Free trade: the great destroyer. In J. Mander & E. Goldsmith (Eds.), *The Case Against the Global Economy and For a Turn Toward the Local*. pp. 218–228. San Francisco: Sierra Club Books.

Newman, L. 2005. Uncertainty, innovation, and dynamic sustainable development. *Sustainability: Science, Practice, & Policy* 1(2):27–31.

Newman, L. 2007. The energy pantheon: challenges and advantages of a diverse energy future. In A. Khare (Ed.), *Energy Management and the Environment: Challenges and the Future*. pp. 75–86. Edingen-Neckarhausen, Germany: Fachbuch Verlag Winkler.

Newman, L, Waldron, L., Dale, A., & Carrier, K. 2008. Sustainable urban community development from the grass roots: challenges and opportunities in a pedestrian street initiative. *Local Environment* 13(2):129–139.

Nichol, L. 2003. Local food production: some implications for planning. *Place Theory & Practice* 4(4):409–427.

Norgaard, R. 1994. *Development Betrayed: The End of Progress and a Co-evolutionary Envisioning of the Future.* New York: Routledge.

Olsson, P., Folke, C., & Berkes, F. 2004. Adaptive co-management for building resilience in social-ecological systems. *Environmental Management* 34(1):75–90.

Oram, J. & Doane, D. 2007. Size matters: the need for human scale economic institutions for development. *Development in Practice* 15(3–4):439–451.

Papworth, J. 1995. *Small is Powerful: The Future as if People Really Mattered.* Westport, CT: Praeger.

Peterson, G. 2000. Scaling ecological dynamics: self-organization, hierarchical structure, and ecological resilience. *Climatic Change* 44(3):291–309.

Pietrykowski, B. 2004. You are what you eat: the social economy of the slow food movement. *Review of Social Economy* 62(3):307–321.

Raeburn, P. 1995. *The Last Harvest: The Genetic Gamble that Threatens to Destroy American Agriculture.* New York: Simon and Schuster.

Rammel, C. 2003. Sustainable development and innovations: lessons from the red queen. *International Journal of Sustainable Development* 6(4):395–416.

Rammel, C. & Van Den Bergh, J. 2003. Evolutionary policies for sustainable development: adaptive flexibility and risk minimizing. *Ecological Economics* 47(2–3):121–133.

Raven, R. 2007. Niche accumulation and hybridization strategies in transition processes towards a sustainable energy system: an assessment of differences and pitfalls. *Energy Policy* 35(4):2390–2400.

Redding, S. 2002. Path dependence, endogenous innovation, and growth. *International Economic Review* 43(4):1215–1248.

Ritzer, G. 1996. *The McDonaldization of Society*. Thousand Oaks, CA: Pine Forge Press.

Rockville City Government. 2007. Find Yourself in Rockville Town Center. http://www.rockvillemd.gov/towncenter/index.html. March 4, 2009.

Scheffer, M. & Westley, F. 2007. The evolutionary basis of rigidity: locks in cells, minds, and society. *Ecology and Society* 12(2):36.

Schneider, D. 2001. The rise of the concept of scale in ecology. *Bioscience* 51(7):545–554.

Scumacher, E. 1973. *Small is Beautiful: Economics as if People Mattered.* London: Blond & Briggs.

Seyfang, G. 2007. Growing sustainable consumption communities: the case of local organic food networks. *International Journal of Sociology and Social Policy* 27(3–4):120–134.

Shiva, V. 2000. *Stolen Harvest: The Hijacking of the Global Food Supply*. Cambridge, MA: South End Press.

Shiva, V. 2004. The future of food: countering globalization and recolonization of Indian agriculture. *Futures* 36(6–7):715–732.

Simon, J. 1996. *The Ultimate Resource 2*. Princeton, NJ: Princeton University Press.

Smith, A. & MacKinnon, J. 2007. *The 100-Mile Diet: A Year of Local Eating*. New York: Random House.

Sundkvist, A., Jansson, A., & Larsson, P. 2001. Strengths and limitations of localizing food production as a sustainability-building strategy: an analysis of bread production on the island of Gotland, Sweden. *Ecological Economics* 37(2):217–227.

Tompkins, E. & Adger, W. 2004. Does adaptive management of natural resources enhance resilience to climate change? *Ecology and Society* 9(2):10.

Trainer, T. 1998. *The Conserver Society: Alternatives for Sustainability*. London: Zed Books.

Unruh, G. 2000. Understanding carbon lock-in. *Energy Policy* 28(12):817–830.

Unruh, G. 2002. Escaping carbon lock-in. *Energy Policy* 30(4):317–325.

Van Hauwermeiren, A., Coene, H., Engelen, G., & Mathis, E. 2007. Energy lifecycle inputs in food systems: a comparison of local versus mainstream cases. *Journal of Environmental Policy & Planning* 9(1):31–51.

Vindigni, G., Janssen, M., & Jager, W. 2002. Organic food consumption: a multi-theoretical framework of consumer decision-making. *British Food Journal* 104(8):624–642.

Wackernagel, M, & Rees, W. 1994 *Our Ecological Footprint*. Gabriolia Island, BC: New Society.

Wallgren, C. 2006. Local or global food markets: a comparison of energy use for transport. *Local Environment* 11(2):233–251.

Walker, B., Holling, C., Carpenter, S., & Kinzig, A. 2004. Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society* 9(2):5.

Wilbanks, T. & Kates, R. 1999. Global change in local places: how scale matters. *Climate Change* 43(3):601–628.

Young, O. 2006. Vertical interplay among scale-dependent environmental and resource regimes. *Ecology & Society* 11(1):27.