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The answer is 42 … What is THE question?

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Abstract Much of policy is fast-tracked and driven toward answers. This approach engenders selecting a problem with short-term thinking, offering a narrowly focussed solution, and seldom considering the linkages to other parts of the overarching system. Short-term and 'common-sense' solutions often bear unintended consequences that may produce worse situations over the long term than if no action had been taken at all. The nexus of food, energy, and water illustrates the need for a holistic approach to evaluating alternative environmental management options and settling on policy initiatives. Successful solutions demand that we ask the right questions, and these should be informed by an understanding of how resilience of ecological systems influences the ability to provide ecosystem services and sustainable societal structures. By explicitly tying resilience to sustainability goals and gaging a society's desired rate of use and associated total available stock of ecological goods and services, stakeholders can settle on what 'the' questions are and only then understand what the supporting ecological systems can actually provide in an equitable and economic fashion.

Keywords Wicked problems · Social-ecological systems · Ecosystem services · Clumsy solutions · Resilience · Conceptual models · High gain drivers · Low gain systems

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Introduction

The nexus of food production, energy demand, and water resources (quantity, quality, location, and timing) illustrates the need for a system perspective. A system approach leads away from single-issue solutions and toward policy formulation and response actions that recognize the interconnectedness of these critical challenges facing human societies, locally, regionally, and globally.

Most citizens, especially those engaged in contemporary political discourse or environmental activism, recognize that there are many vexing challenges that deserve attention. Working toward equitable access to and distribution of ecological goods and services will not be easy. But we contend that to succeed in this realm of 'wicked problems' (see Rittel and Webber 1973, Seager et al. 2012 for explanations of wicked problems) requires more widespread understanding of the social–ecological systems in which humans live, work, and play (McCormick 2010). Valuing resilience in ecological systems that support society, when used as a central concept, can guide us in setting upper limits to the rate of flow of goods and services into society such that our activities can be deemed sustainable. Our management actions (such as tilling, planting, harvesting, converting, conserving) do provide ecological services to the landscape but can strongly affect the initial resilience we valued in that ecological system, including, for example, the rate of flow of waste products that we return to our landscapes for treatment or storage.

We address these challenges and seek opportunities for a sea change in the ways policies are developed and environmental management decisions are made by exploring three themes. First, we make the case for intelligently tackling the problems presented by the nexus of food, energy, and water using Donella Meadows (1999) insights into places to intervene in societal matters. Second, we draw from the ecological literature that details system responses to pressures, with a focus on the determinants of resilience. Third, we relate these perspectives on environmental management and system ecology through a discussion of the delivery of ecosystem services as envisioned through the perspective of the single-pillar concept of sustainability (see McCormick et al. 2012).

Hierarchy for intervention

Meadows (1999) states that leverage points are power and that some leverage points are more powerful than others. Leverage points group into three general classes.

The first set places primary focus on structural aspects (numbers, stocks, buffers) that are generally easy to measure and understand. The growth rate of the economy, future discount rates, and Dow Jones Industrial Average are constantly discussed and obsessed over. Yet, any of these usually only vary by relatively small amounts, and those changes, even those specifically gaged to have a resulting improvement on some aspect of society, do not affect the essential nature of the system in which they operate and thus are weak leverage points.

The second set is more process-focused, looking at negative and positive feedbacks and timing of delays between actions taken and system changes observed, leading to the tracking of flows of energy, currency, and information. Inside every negative feedback is a positive feedback trying to get out. Left unchecked, positive feedbacks loop and expand until they destroy the system in which they operate. The technology stock bubble and the home mortgage bubble are two examples of effectively unconstrained positive feedbacks that caused deep system damage. Negative feedback loops are the self-correcting elements of a social–ecological system and are necessary to contain periods of irrational exuberance (Greenspan 1996). This is the point where better understanding of the food–energy–water nexus becomes possible. Right now, more food is produced each year, and the result is more people on the planet each year (positive feedback loop). Drought, famine, disease, war … all are negative feedbacks that can limit both food production and human population growth. These generally work on a local or regional level and are limited in their overall moderating effect.

The rate of human population increase is slowing, but population process (demographics) is in positive feedback mode and will result in a projected population plateau between nine and 12 billion humans by 2050, a mere 35 years from now. Many societies are predisposed to ignore social equity and acquire resources globally regardless of another society's needs, entraining control of even more wealth and power in a minority of the population. Certainly social equity is an element of a more sustainable society, but the ecological elements in tension with economic drivers present the more pressing concern.

As populations in China, India, and South America increase, the number of persons seeking a middle-class lifestyle (European or North American) will increase exponentially. This affluence bubble will increase the demand for food and water from an already hard-pressed ecological system, all of which will require energy and raw materials from the planet's abiotic realm. Those large structural elements expanding outward engender a positive momentum that will soon overwhelm most negative correcting factors. The length of these system lags is interesting to understand but offers only a moderate position of leverage and overall is not very helpful in addressing the root problems.

These types of leverage points (system lags and feedbacks) still assume that the 'current system' is what societies desire to use and want to maintain. Effectively, they work within the existing system rule set and thus cannot change the fundamental nature of the system. Thus, the third, and most powerful, set of leverage points resolve when we ask questions about what the rules of the system are, which ones we can change, what structures can be added or removed, why we ignore some to our detriment, and just what are the espoused (assumed) and operational (actual) goals of the current system.

The espoused goal of most current societies is for the system to make everyone richer (that is, to create more capitalists). In reality, the operational goal of most economies is 'success to the successful', that is, to just accumulate more capital (or acquire more stuff or control more resources) however inequitably. Economic growth has been the operational mantra of the non-Buddhist economics (Schumacher 1966) over most of the last 100 years. Growth is usually measured as the percentage change in a nation's gross domestic product (GDP) year to year and is the benefit side of the material economy. Economic growth has associated ecological and social equity costs. One would think then that the other key indicator would be some measure of decline in purchasing power, ecological services, and social stability. But, no, decline does not rise to the same level of obsession or arises in conversation only tangentially to the "really important" factor on how well a society is doing, the growth rate of the economy. Growth is so clearly on the minds of most societies that they do not even use the term decline, but instead refer to a "negative" growth rate.

These three general sets were listed and described in increasing order of effectiveness. The third set indicates that the most powerful place to intervene in, and change, a system is by questioning the rules and goals of the system to surface the assumptions underlying the working paradigm. Meadows (1999) ended the list of 12 places to intervene with '1. The power to transcend paradigms'. By surfacing assumptions, individuals and societies come to more fully understand what the current system actually does and who or what it serves or benefits. By understanding the operating paradigm, a society can then open the conversation to a dispassionate assessment as to whether to continue using the same system with internal changes or shift to a completely new system. This entails fully questioning just what it is that we want: the vision of a sustainable, locally-to-globally resilient society to be—what it should and needs to be, not just what we can get away with while narrowly avoiding a globe-spanning and catastrophic negative feedback to the global system.

Resilience and sustainability

When humans operated as small bands in a hunting and gathering mode, there was relatively little environmental management needed, though some did occur, as the bands moved on to the next source of high-value food. This was a high-gain epoch in the development of human societies. Abundant food resources were acquired and used as fast as needed and then the area was left to self-replenish while a new area was exploited. Effectively, this was a period of supply exceeding demand, given the ability of bands to move about the landscape as needed.

Acquiring these high-quality food resources required relatively low human energy input. Estimates average around 4 hours a day of human labour for a small band of hunter/gatherers (sensu Sahlins 1968). Eventually, bands grew too large to move frequently and with ease, neighbouring bands may have 'discouraged' their movement, and social infrastructure had become established (trading routes, meeting places). Food demand from an increasing population exceeded supply from a local area, and shift in the food–energy–water nexus was required. The original high-gain foods (meat, nuts, berries) were supplanted by much lower-quality items (grains, roots, tubers). These low-gain foods could be grown, with effort, and stored locally in quantity (Allen et al. 2001). In fact, that switch from high-gain hunting/gathering to low-gain agriculture brought human societies onto the path that became the 6-day work week. The Sabbath remains to this day a (seventh) day of rest, which shows the strength of history and narrative (low-gain organization) to resist the self-organizing energy throughput of an ecological system (high-gain thermodynamics).

Just how wicked is the relationship between our current society and our demand and supply curves of food, energy, and water? Today's linkage of food acquired to energy expended stems from the evolutionary ebb and flow of human societies and thermodynamics. At various times, societies have had access to small amounts of very high-quality energy (high-gain epochs), and when demand exceeded the supply, society shifted to a lower quality but much more abundant energy source (low-gain epochs). Bringing this to the present day and projecting into the near future, it will become clear just how wicked a problem our current society faces and what types of clumsy solutions we might start to test (see Stahl and Cimorelliy (2012) for a discussion of clumsy solutions). From extraction (flaring and spills) to local production (CO_2 and fly ash storage) to distribution (siting and landscape fragmentation), it all leads to politics (where to extract, how to protect a source, what to produce, who distributes, who regulates, what sector inequitably gets the externalized social and environmental costs). While we are using a particularly North American-centric view, the ideas do generalize to any village or ecoregion or country.

Empires rise and fall based on their history and the amount of energy they can maintain flowing through their society (Tainter 1988). Human societies have, since the inception of agriculture, occurred at the nexus of food, energy, and water. Societies have shifted between high-gain and low-gain epochs in response to challenges of supply and demand, primarily of food and water. Notably, Adam Smith's economics (Smith 1776) were entirely influenced by low-gain, highly organized agricultural systems. Just as he finished his influential treatise titled "On The Nature and Causes of the Wealth of Nations", the coal-fuelled era of the steam engine began. The "Engine to Raise Water by Fire" project (Stephenson 2004), a mere footnote in Smith's work, led to the extremely high-gain fossil fuel-driven social–ecological system we have today. The low-gain agriculture of 8000 years ago is still a large part of modern society but is overshadowed by the technology-driven positive feedback system allowing individuals and societies access to food, energy, and water resources virtually anywhere in the world.

Population demographics, in the context of the El Nino Southern Oscillation, Pacific Decadal Oscillation, Inter-decadal Pacific Oscillation, sea level rise, persistent drought, regional conflicts, and globally displaced populations, are driving the global society to a tipping point. Within our existing high-gain fossil fuel-driven and increasingly fossil water-based food production system, there is a tenuous balance with energy and water demands from industrial and residential sectors. Human society will soon have eight billion people living off what the current high-gain tech-dominated food system can produce. But that assumes the continued functioning of the low-gain agriculture-supported system on which it is based. And that system emerged from local societies interacting with what was available in their landscape and grew to become a global system without any real plan, due to ready availability of fossil fuel and fossil fertilizers. As local and global society can no longer rely on a consistent climate to provide consistent flows of low-gain grains into our desired but short-lived high-gain system, a shift to a more highly organized, resilient, and sustainable low-gain system is required (Allen et al. 2001).

'The' question, assuming that the answer is "42" (Adams 1979), is how do we shift a global population reliant on a global economic system to a deeply organized, low-gain epoch. The coming epoch will need ecologically resilient communities that can be disconnected, at will and as needed, from the demands of a global economy, and only reconnect when it is favourable and equitable to do so. This leads to the question of how can a local community value the embodied water in an almond grown in southern California and price almonds accordingly and not need to sell an almond only for what it is worth in Germany? The approach to addressing such wicked resilience problems can be found by answering four questions that will surface both a society's assumptions and some of the operating rules and goals of that society. To establish just what an individual or group means by saying 'this is sustainable', they need to openly and truthfully express what it is they value, why do they value that specific thing, how long do they need their supporting landscape to provide that thing, and what are they willing to pay (Allen et al. 2003). A clear description based on these questions opens up the discourse to the actual 'operational' effects on social equity and alteration to ecological systems their concept of sustainability entails, as well as the typical economic expense that maintains a society's 'espoused' values of what they think they need now and into the future.

For two centuries, so-called developed Western societies have had the luxury of a consistent supply of energy, which provided an ample supply of water, which facilitated growing an abundant quantity of food to a growing society and economy. But the unquestioning devotion to furthering that system has brought us to a nexus of peak energy, peak agricultural output, and a volatile growing-season water supply. It is obvious that 9–12 billion people on the planet will force a shift from our existing high-gain (self-organized) system to another low-gain (human organized) epoch to sustainably deal with the global issue of food and water supply. But that system cannot be organized around food production alone, as the prior low-gain system was. To remain resilient, the next food–energy–water system will need to shift rapidly and often between high-gain and low-gain phases, as new energy sources rise and fall and as water availability oscillates within a changing climate, all driven by the increased demands of an increasing human population.

We need to

- Live within the rules of ecology
- Manage surplus flows of ecological goods and services
- Recognize that the choices we face are value-laden (i.e. not answerable solely using the tools of biophysical sciences)
- Anticipate that change will occur

The question is not how to do this with 8, 9, or 10 billion humans making demands on the system. The questions that need to be addressed should answer if it is desired or even possible to sustain the aspects of the ecological systems on which we derive the myriad of ecosystem services that are essential for the desired quality of life societies seek with a global population of that size. "How do we feed X billion humans?" is not the best question for society to ask. If we ask *only* that question, we as a society fall into our current standard policy development approach that is fast-tracked and driven toward a single, simple solution. This approach engenders selecting a problem with short-term thinking and offering a narrowly focussed solution. Questions focussed solely on how to feed the global population offer a very incomplete conceptual model of what sustainability for any level of society should look like and one that quite probably leads to the elimination of large tracts of wildlands, further stressing the ecological systems on which the global population depends for ecosystem services beyond food supply.

A holistic approach to inform policy and actions

Sustainability is invoked by many companies, governments, and non-governmental organizations. Nevertheless, despite nearly three decades of prominence, the concept remains elusive and confusing to many. This is partly due to differing perspectives of the concept; some focussing on development, others considering sustainability to be a destination, and others holding that it is a process. There are also differing attempts to represent the concept as a variation on three pillars of sustainability (a.k.a. the triple bottom line of environment, economy, and equity; people, planet, and profit) or, more appropriately, as a single pillar.

A criticism of the three-pillar model is that the predominance of neoclassical economics results in an inadequate monetizing of environmental and societal components so that effectively there is only an economic feature present in most social questions (see McCormick et al. 2012 reference to Jody Roberts' presentation on single-pillar concept). The single-pillar model posits that economies are nested within societies and societies are fully embedded within ecological systems (McCormick et al. 2012). This shift in perspective fosters discussions on the delivery of ecosystem services from the ecological systems to societies in ways that invites the use of system ecology and the dynamics affecting resilience.

From ecological science, we know that components of any ecological system are subject to change. The biotic and abiotic components of a system act upon each other and the biotic parts are governed by multiple nested feedback loops—some reinforcing, some dampening the rates of change. These operate on different spatial and temporal scales resulting in greater conceptual complexity. Ultimately, dynamics of the ecological systems in which we reside or take from at a distance determine the flow rate services and that the rate must allow the system to replenish the goods or services supporting the next take. If our rate of demand exceeds the capacity of the system to provide, as a society, we are not acting in a sustainable manner.[1] If the pressures are too great, system resilience may be lost and the system will reset to some other 'stable' state that may be functionally sufficient for its needs but does not provide the ecosystem services that our dependant society needs. That is the problem and is usually wicked in its formulation.

The ability to reach into any corner of the planet and produce a needed material from the global resource base allows our current society to live in a state far from equilibrium with our local landscapes. This reach also allows us to occupy marginal lands and those areas that would not support even the smallest of communities. Living in marginal lands and importing food, fibre, and energy places great demand not only from the goods side (the rate at which the system supplies desired food, water, and other materials) but also from the services side (the assimilation rate of societal wastes).

There remains much uncertainty regarding how to universally define sustainability, what tools and approaches are helpful or harmful, how to measure successes, and how to meaningfully engage stakeholders.

The cultural meme that sustainability or sustainable development is a societal necessity must also be assessed critically. Sustainability is only a necessity if we as a global society wish to avert black swan events that would force the unplanned and uncontrollable reordering of how societies interface with their environment. We actually need do nothing, as eventually the ecological system will provide feedback to our demands in a manner that drives decisions for us.

There are a number of intriguing projects that have been implemented over the years with a focus on improving energy independence and food security or providing ample water. For the most part, these have been single-issue efforts with only passing consideration of the connections between other valued resources.

- The National Petroleum Reserve is over 40 years old as a concept and was intended to buffer the US Navy (originally) and now the entire USA from an embargo or other disruption of oil imports to domestic refineries, yet, over that time, we have not fully tested our ability to physically re-distribute oil from the Gulf Coast to more northern refineries.
- Nuclear missile silos and control centres were placed in remote area of North Dakota in the 1960s. In the last few years, wells and railways extracting and transporting Bakkan oil have encroached on the nuclear facilities posing risks that concern the US military. Somehow, the drive to increase oil production overshadowed the need to establish 'no-go' buffer zones around the nuclear facilities.
- In the midst of the water crisis in California, petroleum companies have been permitted to use large quantities of water for hydraulic fracturing and dispose produced water including fracking fluids into aquifers.
- Almost every dam built in the Pacific Northwest had been planned with fish ladders to allow salmon passage, yet most were never built, usually due to short-term economic considerations.
- Genetically modified organisms (GMO)—corn producers were originally required to put in non-GMO buffer crops to prevent the spread of the genome to other corn varieties. Those buffers were never effectively established or maintained. Today, there are almost no corn seed that does not have some genetic material from GMO strains.
- After less than two decades of the almost exclusive planting of transgenic crops resistant to the herbicide glyphosate, with the promise to optimize weed control by making it simple, easy, and cheap, glyphosate resistance in weeds has forced farmers to go back to older, more costly forms of weed control, including stronger herbicides to deal with the now hardier weeds.

These are only a few examples of where simple, obvious, short-term solutions seemed at the time to be sufficient, but in complex social–ecological systems present wicked problem spaces, and good intentions do not survive long in those environments. We need to re-train our decision process to acknowledge this reality and to re-learn how to make resilient and sustainable social systems.

Resilience approach works from a standpoint of understanding system processes and the flow of material and information with no set end goal in mind. Sustainability recognizes the current system and, through a dialogue based on four sustainability questions (what is to be sustained? How long? Who benefits? and What are the social and economic costs?), posits scenarios of desired future states. These can be aimed at retaining what is currently operational or moving the trajectory of the system toward agreed desired conditions. All policies need to address the process by which things can change and the structural changes to a social–ecological landscape that supports a society. We do not always know how to frame 'the' direct question, but we do know it must include current and possible future condition states such as stakeholder polarization, time lag between understanding and acceptance of the problem and the potential solutions, the troubled waters of discussing human population demographics and migrations, and the arcane and mundane day-to-day technical issues underlying efforts to supply water, food, and energy to the 7+ billions on the planet today.

Real-time examples illustrate the complexity of these issues, including management of the Strategic and National

[1] Note that if we take nothing, the system is still subject to change in ways that may be or may not be desirable to some stakeholders.

Petroleum Reserves, Pacific Northwest salmon and hydropower, diamond mines in the Northwest Territories, and restoration in the Everglades. In the desire to see quick and certain progress, we as a society trend toward engineering solutions that address a particular problem. Examples abound in which the collateral responses (a.k.a. unintended consequences) spawn new problems that as viewed by many stakeholders are worse than the initial situation.

The way forward that has a better chance of achieving equity among stakeholders is to adopt holistic, integrated system approaches. This entails investing the time and energy to hear from diverse groups of stakeholders. This requires patience so that an agreed conceptual model or mind map of the ecological system and the relationships that the stakeholders have with that system can be developed. The state of affairs needs to be vetted sufficiently so that the actual or perceived problems can be described sufficiently so that it is possible to identify *the question*. We must resist the seductive drive to offer up answers before the effort has been made to frame the question.

Some, especially traditional scientists and engineers, find this approach to be quite disturbing. There is an apparent thread of impatience woven into their being as the push to get on with the 'obvious solution'. However, we should know from past adventures that as wonderful as many advances have been, engineering fixes that are not deeply grounded in the culture of the affected stakeholders can be quite disruptive. Contemporary challenges require the new approaches described as post-normal science; this embraces fully transdisciplinary efforts to frame the questions so that policies and practices embrace the strictures of system ecology and can result in more resilient and more sustainable outcomes.

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