AMBIO (2011) 40:762–780
DOI 10.1007/s13280-011-0186-9

INVITED PAPER

Tipping Toward Sustainability: Emerging Pathways of Transformation

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Received: 29 June 2011 / Accepted: 29 June 2011 / Published online: 6 October 2011

Abstract This article explores the links between agency, institutions, and innovation in navigating shifts and large-scale transformations toward global sustainability. Our central question is whether social and technical innovations can reverse the trends that are challenging critical thresholds and creating tipping points in the earth system, and if not, what conditions are necessary to escape the current lock-in. Large-scale transformations in information technology, nano- and biotechnology, and new energy systems have the potential to significantly improve our lives; but if, in framing them, our globalized society fails to consider the capacity of the biosphere, there is a risk that unsustainable development pathways may be reinforced. Current institutional arrangements, including the lack of incentives for the private sector to innovate for sustainability, and the lags inherent in the path dependent nature of innovation, contribute to lock-in, as does our incapacity to easily grasp the interactions implicit in complex problems, referred to here as the ingenuity gap. Nonetheless, promising social and technical innovations with potential to change unsustainable trajectories need to be nurtured and connected to broad institutional resources and responses. In parallel, institutional entrepreneurs can work to reduce the resilience of dominant institutional systems and position viable shadow alternatives and niche regimes.

Keywords Social-ecological systems · Innovation · Transformation · Resilience transitions · Sustainability

INTRODUCTION

Humanity has entered the Anthropocene era; human activity has become a major driving force in the history of the planet. The future of human well being may be seriously compromised if we should pass a critical threshold that tips the earth system out of this stability domain (Rockström et al. 2009).

Humankind's problems are rendered more difficult by the rebound effects on societies of human perturbations of key processes in the earth system such as: (1) global nitrogen, sulfur, and carbon cycles; (2) the declining availability of resources critical to human well being like fresh water, rich cropland, and high-quality energy; (3) the rising complexity, interconnectivity, and speed of operation of key global social-ecological systems, including the world's financial, trade, food, and resource-extraction systems. As a result of the foregoing three trends, there is a rising frequency of threshold behavior in these key systems. It is plausible that current development paradigms and patterns, if continued, would tip the integrated human-earth system into a radically different basin of attraction (Steffen et al. 2007).

Scientists concerned about the future of the planet have pointed to the urgent need for sustainability transitions (Clark 2001; Raskin et al. 2002). They recognize that these may require radical, systemic shifts in deeply held values and beliefs, patterns of social behavior, and multi-level governance and management regimes. In addition, we will need to harness human creativity and innovation potential

The article is based on Westley et al. 2011. Tipping toward sustainability: emergent pathways of transformation, Working Paper No. 3. Prepared for the "3rd Nobel Laureate Symposium on Global Sustainability: Transforming the World in an Era of Global Change", in Stockholm, 16–19 May 2011. Stockholm Resilience Centre, the Royal Swedish Academy of Sciences, the Stockholm Environment Institute, the Beijer Institute of Ecological Economics, and the Potsdam Institute for Climate Impact.

to tip the interlinked social and ecological systems in the direction of greater resilience and sustainability.

In this paper we ask the question:

> *Can we innovate sufficiently rapidly and with sufficient intelligence to transform our system out of a destructive pathway and into one that leads to long-term social and ecological resilience*?

We define resilience as "the capacity of a system to absorb disturbance and reorganize while undergoing change, so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker et al. 2004; Folke et al. 2010) and transformability as the capacity to create untried beginnings from which to evolve a fundamentally new way of living when existing ecological, economic, and social conditions make the current system untenable (Walker et al. 2004; Chapin et al. 2010; Folke et al. 2010, 2011). We argue that a complex system perspective that recognizes the dynamic links between the social, ecological, and technological subsystems is needed to understand what we see as the paradox of innovation: innovation is both a contributing cause for our current unsustainable trajectory and our hope for tipping in new more resilient directions.

THE INNOVATION PARADOX: A DOUBLE-EDGED SWORD

Historically, humanity has put great faith in technological innovation to help transform societies and improve the quality of life (examples include the industrial revolution, the more recent Green Revolution and the Internet Revolution). Starting with the liberalized market, during the Thatcher and Reagan era in the 1980s, the belief that the free market would deliver innovation and improve the quality of life for everyone quickly became a dominant policy paradigm across most of the Western world. The European Union and its member states put in place policies and legal frameworks requiring the deregulation of infrastructures such as telecom, railways, and energy. The experiment proved disappointing. Simple deregulation did sometimes result in accelerated innovation in, for instance, communication, transportation, and alternative energy, but primarily led to an optimization of existing systems rather than to system innovations toward sustainability.

Nonetheless, we have not entirely lost our confidence in the technological "fix," nor should we (Allenby 1993). Questioning innovation goes against the grain of our current worldview and the societal and governance structures that rule our lives. Invention (the creation and implementation of new ideas) and innovation (the spread of the latter in society) have in our system served as the principal means of economic value creation, rather than as a means to reduce our impact on the biosphere, our life-supporting environment. The spread of material wealth all across the world is closely tied to the maintenance of the social peace enjoyed by western countries. Indeed, western society has become dependent on material innovation and the attendant value creation to maintain its political and social systems. There are good reasons why we place faith in our capacity to innovate; it has been associated with a better quality of life for all.

There is no doubt that achieving sustainability will require better technologies (Allenby 1993; Graedel and Allenby 1995). Today, attention is focused on measures such as publicly funded demonstration projects in carbon capture and sequestration, or support for niche-markets developing renewable energy sources. Scientists, decision makers, and concerned citizens repeatedly turn to industries such as biotechnology and nanotechnology, in the belief that innovation in those domains may offer the solution to everything from food scarcity to global pandemics and climate change. The fact that, in free market societies, much of the capacity for technological innovation resides in commercial enterprises points to the private sector as a key actor in the creation of new pathways to sustainability (Allenby and Richards 1994).

However, there are warning signs that suggest that technological innovation, far from serving our needs, may indeed be driving development in directions directly opposed to sustainability (van der Leeuw 2010). We may be "locked in" to a technological innovation trajectory reinforcing the current path. Continued innovation is needed to keep creating new value, so that the economic system can expand, and nations can claim increases in GDP and wealth. Any slowing down, or shrinking, of the economy has become stigmatized as "backsliding," that is liable to lead to a crisis. Despite suggestions by environmental economists, that growth should be treated as a way to arrive at a more balanced valuation of economic, environmental and social quality (van den Bergh 2010), we remain committed to economic growth that allows for the unbridled demographic growth of the last century (Lane et al. 2009).

This, in turn, has encouraged and produced an almost unchecked acceleration in the pace of innovation, accompanied by the emergence of unintended consequences. Whatever form a transition to sustainability might take, it implies finding the institutional frameworks to stimulate the kinds of innovation that solve rather than augment our environmental challenges (Steffen et al. 2011).

This may prove difficult in practice, for a variety of reasons. First, the problems we are facing are so complex that it is hard for us to grasp their dimensions—there is an

"ingenuity gap" between the demand for appropriate solutions and its supply. Second, the nature of technological innovation processes is in some ways inimical to the nature of a healthy environment; and further, the path dependent (vs. path breaking) character of technological innovation means there may be a lag between what we see as an emerging crisis and the available technological response. Finally, the sector most likely to produce innovative technical responses to environmental threats, the private sector, is constituted as the engine of economic growth and is unlikely to place that innovative capacity at the service of greater sustainability unless broad institutional shifts occur to encourage such reorientation.

The Ingenuity Gap

There are many limits to human ingenuity. In particular, the sheer complexity of linked social-ecological systems makes it difficult to respond adequately. Surprise is common and by definition unanticipated. Our interventions in the broader life-supporting environment are based on a limited knowledge of that environment, and our impact on that environment has many dimensions that are unknown to us. The disproportion between the known dimensions on which we base our actions and the unknown dimensions that are affected by these actions is directly related to the relationship between the (relatively small) number of dimensions that we recognize, and the (relatively large) number that we do not. Hence, the increase in our knowledge about our role in the environment cannot keep pace with the increase of the unknown impact of our actions on that environment. If the former might at most be geometric, the latter is more likely exponential (van der Leeuw 2010). This is reflected in the great acceleration of human activities and its imprints on the biosphere (Steffen et al. 2011).

Humankind's innovation challenge can be understood in terms of an "ingenuity gap" between the increasing seriousness of the world's problems and the lagging supply of solutions to those problems. Homer-Dixon (1995, 2000) defines "ingenuity" as sets of instructions that people use to arrange the things in their world (including materials and other people) to solve their problems. As our world's problems become harder, our *requirement* for ingenuity—measured by the length and complexity of the sets of instructions we need to address our problems—rises. Too often now, it seems, we cannot *supply* this required ingenuity. Indeed, it can be argued that our current institutional arrangements, including the institutional pressures and incentives (governance regimes, market incentives, and cultural values) that attract and shape the emergence of both technical and social innovation, mediate *against* an appropriate and creative response to complex challenges.

The Antagonism Between the Organization of Technology and the Organization of the Biosphere

As argued by Folke et al. (2011), the conceptual and institutional separation of social and ecological systems has contributed and continues to contribute to a misfit between ecosystems and governance systems. This separation is a strong contributor to the path dependence that makes it is so hard to shift to sustainable trajectories. Nearly two decades ago, Commoner (1993) pointed out that the "technosphere," the innovative engine that has driven the modern economy, is organized along lines very different from and even contrary to the functioning of the "biosphere". Commoner summarizes four points of contrast: (1) the cyclical nature of ecological processes versus the linear, means-end reasoning that characterizes the technosphere; (2) the biosphere represents a dynamic equilibrium in the exchange of matter and energy, destruction, and creation versus the technosphere's orientation toward profit maximization through the externalization of environmental and social costs; (3) in the biosphere, parts are fundamentally interdependent versus the technosphere, where single variable interventions without reference to system impacts and interactions are the rule rather than the exception; (4) elements of the biosphere by nature evolve in relation to each other to achieve system integrity versus the idea that growth of separate parts, irrespective of the system, is a good and limitless possibility (Commoner 1993, pp. 8–13). The introduction of the automobile, greeted as an extraordinary innovation, is often cited as an example of failure to consider the possible system consequences of a single technology.

For these reasons, among others, technological and economic solutions to global environmental challenges are often inimical to the health of the biosphere. For example, a systemic shift to biofuels was initially greeted as a breakthrough in sustainable energy production. The private sector interest was immediate, and today, the biofuel industry is poised to become a trillion dollar operation. Little attention is being paid, particularly in the government sectors concerned with technology and the economy to the potential unanticipated consequences including, loss of land now used for subsistence agriculture and the famine associated with its loss and the biodiversity loss associated with mono-crops (Grau and Aide 2008; ETC Group 2010).

Another example is the release of new hybrid and genetically modified cereal seed varieties in African settings. In recent years, a discernable shift toward risk-based framings (DeWulf et al. 2007, 2009) has become evident in dominant policy narratives around the introduction of GM crops in particular countries and in regional debates on stimulating a new Green Revolution for Africa (Scoones

and Thompson 2011). Along with narratives that emphasize "drought tolerant" (non-GM, hybrid) and "water efficient" (GM) seeds as solutions to problems of hunger (a common narrative widely promoted by the seed industry and others) have come pressures from the international agricultural research community, government, and civil society actors alike, to seriously address the areas of incomplete knowledge surrounding these technologies, their application, and potential impacts. In the case of drought tolerant seed varieties, on environmental change and maize innovation pathways in Kenya has shown initiatives that rely on a linear "pipeline" innovation approach (and its associated regulatory framework) remain locked-into a risk-stability management model. Despite their use of a language of "adaptation" and "resilience", such models are unlikely to match, let alone enhance, the adaptive capacity of households and communities in marginal environments. In particular, interventions focused on strengthening and extending the formal maize system at the expense of local, informal systems threaten to undermine those sources of diversity from which people in different localities need to draw if they are to build livelihoods that are both resilient to shocks and robust in the face of longer-term stresses (Brooks et al. 2009; Thompson et al. 2010a, b).

Last is an example of the unintended consequences of a seemingly successful national reforestation program (Fig. 1). Several developing countries have recently achieved a national scale shift from net deforestation to net reforestation, with a simultaneous increase in food production: China, Vietnam, India, Bhutan, Costa Rica, El Salvador, and Chile. Understanding the conditions associated with these land use transitions is rich in policy lessons. Most of these countries experienced a growing total population, with a decreasing or stable rural population. Crop yields increased, and the total agricultural area generally expanded. Protected areas have also expanded. Forest plantations contributed a large share of the expanding forest cover in Chile, Vietnam, and China. The round wood production in these countries declined or remained stable. All these countries displaced some of their land use abroad as they were going through a land use transition: additional global land use change in neighboring countries, embodied in their wood imports, did offset more than half of their total reforested area. This unintended consequence of forest protection in one country context

Fig. 1 Reforestation in one country may be offset by wood imports from other countries (photo Carl Folke)

decreased the global environmental benefits of national land use policies (Lambin and Meyfroidt 2011).

The Lag Created by Supply Driven Innovation, the Path Dependent Nature of Technology, and the Institutional Context of Innovation

For much of human history, invention (the creation and implementation of new ideas), and innovation (the spread of the latter in society) were relatively de-coupled events. A millennium elapsed, for example, between the discovery of ironworking in Europe and its wholesale adoption. During that time, an old social order (based on control of localized copper mines) came to an end, so that a new social order (based on using omnipresent iron) could emerge. In essence, innovation was demand-driven.

In Europe, this began to change in the 17th century. Girard (1990) describes how—over the last three centuries (the period of the Enlightenment and the Industrial Revolution)—a western attitude that valued continuity and explained the present with reference to "history" was transformed into one in which "innovation" is prized and the new (and unknown) is preferred over the older (and known). During this time, we see a number of profound changes in the process of invention and innovation that correspond to major changes in our societies (Lane et al. 2009). Two are of particular interest here.

First, innovation gradually became supply driven rather than demand-driven. Today, interesting new ideas or tools spawn companies that invest in marketing to stimulate product demand. "Need" is created. Second, the new ideas or tools are in themselves driven by the availability of pre-existing technology platforms. As Arthur (2009) has pointed out, new technologies do not spring from the air; they are combinations of technological elements or sets, which are in turn combinations of previous elements or sets. Hence, when radical new social or ecological problems arise, whether in the form of pandemics or of climate change, our capacity to innovate in response is hampered by a history of technological path dependency and a culture of supply driven innovation. This comes close to technological lock-in, reinforced through several forms of positive feedback (Kaiser 2003; Walker et al. 2009), including social, legal, and economic variables.

Particularly important for innovation are those feedbacks that guide the behavior of the private sector firms. Since the 1980s, there has been a call for business to pick up what governments largely no longer do. Business, goes the argument, should address society's environmental concerns, and social concerns. In doing so business can unleash a cascade of innovation and productivity gains (Porter and Kramer 2011).

However, business has evolved, especially since the 1950s, in a way that limits its possible contribution to wider societal challenges. Whereas previously the role of business was to provide a stable flow of services, goods and employment, the post-war demographic and economic growth has put economic success and shareholder value at the heart of business entrepreneurship. This in turn has evoked business behavior focusing on optimizing shareholder value and externalizing cost. A business community that is itself locked in an unsustainable growth-oriented regime can only play a constructive role in accelerating the desired transitions when this one-dimensional focus no longer confers competitive advantage. Although, there are signs that in some sectors this is increasingly the case (resource intensive industries, food, construction, and energy), it will require clever strategies on the part of governments and civil society organizations to create conditions under which businesses that create broader social value are favored over businesses which only focus on their own economic value creation (Loorbach et al. 2010). Contextual or institutional changes can make innovation for sustainability more attractive in two ways: (a) NGO and public pressure can increase the costs of *not* innovating and (b) government can change the rules through negative and positive sanctions and stimuli so that investment in such innovation potentially pays off in new business or investment for the company.

NGO pressure on large stockholder-owned western companies can affect the strategy of those companies. Canadian oil company Talisman Energy, despite their genuine and skillful efforts to meet international NGO demands, saw their share prices drop as international NGOs campaigned against their operation on the grounds of its impact on ethnic/religious minorities in southern Sudan. Eventually, the company was driven out of Sudan. International resource companies increasingly operate on a global stage where their mistakes can be amplified to the point of driving them out of the marketplace (Petersen and Vredenburg 2009).

Without such NGO pressure it is often difficult for firms to justify the cost of innovation. Events such as the Exxon-Valdez oil spill and Shell Nigeria's involvement in civil strife have drawn public indignation resulting in much greater engagement of international oil companies in community projects and collaborations. This in turn has indeed driven innovation (Moser 2001). Engagement with stakeholders, while difficult and ambiguous, often adds value, providing firms with new viewpoints, knowledge, and networks. As firms develop skills in the process of engagement and co-creativity, they gain a competitive advantage that is hard to replicate (Hall and Vredenburg 2003; Higginson and Vredenburg 2010).

Ultimately, however, in order for business and the market to play a truly innovative role in major sustainable development systemic change, beyond paying it lip service, a market must be created for the services or products concerned. This is a complex social and institutional process that needs the collaboration of business, government, and other civil society actors. Part of that process is the creation and enforcement of standards, so that a "level playing field" is created that in turn makes investment in innovation contributing to systemic changes toward sustainability worthwhile for the firm. Enforcement can be effected through either penalizing non-compliant firms or through favoring, through quicker regulatory approvals, innovative, and proactive firms. Regulation, if enforced by the state or by appropriate targeted NGO pressure, is a proven stimulus to innovation (Strebel 2004).

TIPPING TOWARD SUSTAINABILITY: UNDERSTANDING AND SUPPORTING INNOVATION AS A MEANS TO TRANSFORMATION

Societal change comes about as a consequence of the interaction between organizations and institutions (North 1990). Institutions are the formal rules and informal social norms that society places upon organizations. Cultural institutions, economic institutions, and governance institutions all play a role in preventing or enabling transformation. They embody the macro level rule sets that frame the behavior of organizations, from governments to private firms as well as that of civil society (Giddens 1976). As we have noted above, the current rules governing the private sector and the economy are not likely to support innovation for sustainability. Similarly, our culture of consumption and growth stimulates behavior antithetical to tipping our systems in the direction of sustainability.

Change demands innovation across multiple scales. At the macro institutional scale, we need to transform our global and national institutions, from a pattern that supports environmental destruction to one that favors long-term resilience and sustainability. At the meso or problem domain scale, we need to create opportunities to incorporate novelty and innovation. At the microscale of individuals and small groups, where invention originates and where the early source of support for "disruptive" or "catalytic" innovation may be found (Christensen et al. 2006), we must foster mechanisms and agency that can connect a healthy supply of invention, with the institutional opportunities that emerge.

Innovation studies from the domains of business, technology, and organizational behavior, have long established the importance of approaching innovation from a top-down/bottom-up perspective. In large, continuously innovating firms, the strategic apex sets strategic direction, but innovation occurs at the front lines, on the shop floor, or in small designated teams. Top management does not so much "control or direct" the innovation process, as provide resources and opportunities for exploration and experimentation (Nonaka and Nishiguchi 2001; Westley 1990). There is a key role here for intermediaries, or knowledge brokers, at the middle management level, who are able to question the strategic context to understand why and where a firm wishes to move, frame that for those working on the front lines, identify promising innovations, and sell these to the strategic apex (Nonaka and Takeuchi 1995; Burgelman 1983). This is sometimes called management up-down or "sandwiched" innovation (Lane et al. 2009). When innovative ideas are connected to strategic priorities this produces the cascade of resources required to bring innovation to markets and scale it up.

In the greater complexity of social and technological innovation designed to address broad system concerns such as sustainability, there are similarities and differences with the corporate innovation model. The emerging work on successful social innovation focuses on the dynamics of scaling up new ways of thinking, new processes for action and decision making, new designs for behavior and new social programs (inventions) for greater durability and impact. This study recognizes significant differences between the dynamics of technological innovation within firms and those of social innovation, including the greater complexity that decouples such innovations from markets and the role of governments as intervening actors (Westley and Antadze 2010; Moore and Westley 2011; Hillman et al. 2011). However, central to both is the role of individuals with particular skills, and the need to focus on cross scale interactions to gauge which innovations have high impact, durability, and scale (Fig. 2).

Three inter-related levels are identified: regimes, landscapes, and niches (Geels and Schot 2007; Markard and Truffer 2008). *Regimes* are the dominant rule-sets supported by incumbent social networks and organizations and embedded in dominant artifacts and prevailing infrastructures, of say, particular industries or social problem arenas. *Landscapes* provide the environment in which regimes evolve. They consist of features like the geographical position of the land, climate, and available resources, and "softer" features like political constellations, economic cycles, and broad societal trends. Landscape factors are a major source of selection pressure on dominant regimes, and so, as landscapes shift, so do the possibilities for innovation and scaling-up of innovations. Radical innovation originates in *niches*: small protected spaces in which new practice can develop, protected from harsh selection criteria and resistance from prevailing regimes. Transitions

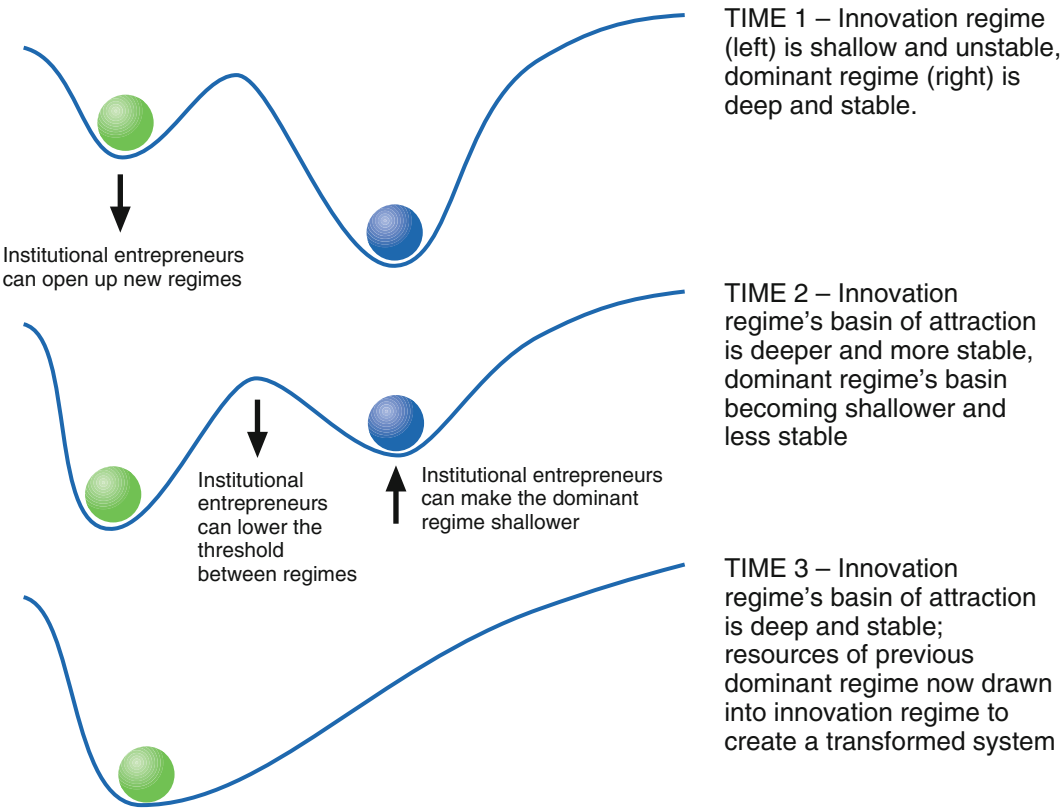

Fig. 2 Cross-scale dynamics of social (systemic) innovations and the role of institutional entrepreneurs. Institutional entrepreneurs are key to systemic transformation. Their role is to question the institutional context, frame it for those working at more microscales, identify those inventions with potential to tip systems and sell these to institutional decision makers when the opportunity arises

(changes from one stable regime to another) are conceptualized in the model as occurring when landscape pressures destabilize prevailing regimes, providing breakthrough opportunities for promising niches. This implies a non-linear process of change in which, after passing critical thresholds, elements of a previously dominant regime recombine with successful niches into a new dynamically stable configuration (Rotmans and Loorbach 2009).

Transitions can be triggered, however, by a "disruptive" or "catalytic" innovation, one that addresses the needs of those not served by the dominant institutional and organizational systems, including the governance system (Hwang and Christensen 2007). A good example is that of the growing success of ecosystem-based management. While, in some governance regimes, notably the United States marine zoning and shifts to ecosystem-based management have been severely constrained by inflexible institutions, lack of public support, and difficulties developing acceptable legislation (Crowder et al. 2006), in many others new integrated management systems, like adaptive co-management and ecosystem-based management, are emerging and being institutionalized around the world (Garaway and Arthur 2004; Armitage et al. 2007; Olsson et al. 2008; Berkes 2009; Cundill and Fabricius 2010).

Disruptive innovation has a fundamentally different relationship to system transformation than the innovation process identified in the corporate innovation literature and described above. The latter results in a continuous supply of novelty that may build resilience of the firm, and even the industry, but does not fundamentally disrupt it. From a systemic innovation viewpoint, this is the equivalent of ideas that take advantage of opportunities at the regime level but do not fundamentally challenge the broader landscape or institutional level that defines and constrains the problem domain. For example, an innovative program designed to address the needs of the homeless, may provide new technology such as "portable homes" to people living on the streets, but only confirms the resilience of the broader institutions that produce and reproduce the homeless problem, such as our built environments and our property regimes. At a local scale, it could be argued that the Transition Town movement, strong in the UK in particular, represents a deliberate effort to "decouple" from the broader economic and institutional system to secure local resilience in the face of possible collapse of the broader system (Barry and Quilley 2009). While undoubtedly innovative, these initiatives are unlikely to stimulate the great transformation toward sustainability

that we need to avoid pushing the earth system beyond planetary boundaries. For that we need a disruptive innovation, a broad system adjustment to allow for its growth and impact and institutional entrepreneurs who connect the two and help to navigate the transition.

Top Down: Shaping the Context for Emergence

In social innovation contexts, like the ecosystem-based management initiatives described above, setting the conditions works better than setting down rules. Like innovation in the corporate context, research suggests that adaptive learning approaches, allowing for exploration and experimentation, are better suited for ecosystem-based management than are rigid approaches that have set prescriptions for resource use (Garaway and Arthur 2004; Pahl-Wostl et al. 2007). Corporate strategies aimed at innovating for sustainable development, for example, are encouraged by laws and regulations that reflect social expectations, as opposed to traditional attempts to compel change (Kenny et al. 2011). Reflexive law, as it is called, is less rule-bound and recognizes that as long as certain basic procedural and organizational norms are respected, participants can arrive at positive outcomes and self-correct (Sheuerman 2001). In response to growing complexity, the detailed rules that regulated entities have been expected to follow are replaced by procedures designed to encourage thinking and behavior in the right direction, while allowing individuals to meet social norms in their own way (Orts 1995). The recent appearance of reflexive law in natural resource industries heralds an innovative role for governments, and a way that government and business can move forward in dealing with global societal issues.

Behaviors of corporations as well as citizens are more likely to change if the context of negative and positive sanctions is changed, rather than through direct or indirect appeal to attitudes and values (Aronson 2008) through scare tactics or other means (Feinberg and Willer 2011). Recent studies of developing and developed economies, and oil-based and non-oil-based economies, give evidence that citizen support for renewable energy can be garnered through linking it to jobs. In Costa Rica, job prospects were linked to "green" tourism. In Denmark, the job prospects created by reducing the country's dependence on unreliable foreign sources of fossil fuels had a similar effect (Espinoza and Vredenburg 2010; Fig. 3).

Tax incentives, subsidies, and competitions or challenges are also ways to focus public support and private sector ingenuity on societal challenges from climate change to biodiversity loss (Moore and Westley 2011). One of the early insights of resilience theory was the need for adaptive management, which in turn called on governments to think of policy as experiments (Holling 2001). Recently, National Endowment for Science, Technology and Arts (NESTA), a government sponsored think tank operating in England, issued a Big Green Challenge. For the prize of one million pounds communities were invited to submit innovative plans for carbon reductions. Over 100 communities submitted proposals that were ranked on innovation and feasibility. Ten were accepted and the communities given some assistance in launching their initiatives. The experiments were diverse and interesting. While, the winners received significant monetary rewards, even the losers had innovative projects underway at the close of the competition (NESTA 2010).

The UNESCO's Man and the Biosphere Program is an international program that offers a framework for stimulating sustainable development. This includes the World Network of Biosphere Reserves. Each reserve or site (564 sites in 109 countries as of April 2011) constitute a platform for learning on sustainable development and a place to experiment with various forms of integrated approaches for managing and governing natural resources and ecosystem services (Schultz et al. 2011; Nguyen et al. 2011). Experiments such as these can help prepare for a transformation by "beta testing" alternative policy options. Innovations of this kind are not necessarily only local phenomena, but can have large-scale effects through diffusion or scaling up, like the suggested re-greening of the Sahel (Reij and Smaling 2008) or targeted grazer control during El Niño Southern Oscillation events to restore degraded ecosystems (Holmgren and Scheffer 2001). The diffusion dynamics of innovation, and their potential positive and negative externalities, highlight the need for global level support of innovation, guided by overarching governance principles for resolving conflicts and facilitating coordination in institutionally fragmented settings (Olsson and Galaz 2011).

All this points to the need for "adaptive governance" in situations, such as ecosystem-based management that require integrated management approaches (Dietz et al. 2003; Folke et al. 2005). The more successful adaptive governance systems, often emergent and self-organizing, connect individuals, networks, organizations, agencies, and institutions at multiple organizational levels with ecosystem dynamics (Folke et al. 2005; Bodin and Crona 2009; Berkes 2010). It is important to stress that transparent, and inclusive decision-making processes that are viewed as legitimate by stakeholders, are a precondition for effective adaptive governance systems to emerge and be sustained over time despite social and ecological uncertainty and surprise. This is in line with the findings of scholars in transition management (e.g., Grin et al. 2010; Loorbach 2010) who argue that the ability to co-ordinate experiments that contribute to system innovation is of crucial importance in releasing lock-ins and enabling shifts to new

Fig. 3 Wind energy as part of sustainability transitions? Öresund, Baltic Sea (photo Mathias Andersson, Azote)

trajectories. Such "systemic experiments" should broadly focus on broadening the diversity of options, ideas, organizational settings, and practices (see for example Bormann and Kiester 2004; Rudd 2004). In other words, building resilience requires systemic experimentation and innovation and this in turn requires enabling those closest to the problem to shape and define solutions.

Bottom Up—Harnessing the Innovative Potential at Local Scales

While government policies, laws, and governance systems can be more or less stimulating to the emergence of innovation and novelty, it is worth remembering that there are natural sources of resilience and innovation in most social systems, overlooked by top-down approaches. A good example is presented by studies of communities in post-conflict Eritrea following the border war with Ethiopia. International aid organizations, sent in by the United Nations to support women in displaced persons camps, were met with some resistance and confusion when they sought to deliver the standard relief package, including treating the refugees for post traumatic stress and alleviating the famine conditions with food supplies. When researchers inquired about suspected psychological trauma, they were surprised to find that despite emotional distress caused by the war and subsequent loss of their homes, the Eritrean women in particular did not consider themselves depressed or traumatized. In fact there is no word for depression in their language; the closest approximation is "*yemenfes chinquet*" (oppression of the soul), a condition seen as originating from social rather than biological causes (Almedom et al. 2003; Almedom 2004). If you have "oppression of the soul", you work hard to tell your story—an important cultural tradition in Eritrea—and this connection to a broader community restores a sense of coherence. Storytelling workshops would have been an innovative response to displacement, but were not imagined in international response protocols.

Local innovative capacity is enhanced when conditions for social learning are present, particularly when there are stores of social memory on which to draw. A study of

innovative responses to disasters in England underlined the need for government to relinquish orchestrating and planning and instead "engage" (listen and learn about local ideas), "educate" (inform local populations of resources and possibilities available), "empower" (trust in the potential and resourcefulness of local communities, including their long-term memory of traditional responses), and "encourage" (allow a diversity of innovative responses to emerge, as opposed to insisting on a top-down planning process) (Edwards 2010). Social learning and social memory prove to be excellent sources of innovation, if nourished and engaged (Barthel et al. 2010). Similarly, the SARS crisis in Toronto was used as a learning opportunity for public officials to identify the hospital cultures that showed the greatest capacity to innovate in response to crisis. It turned out that these hospitals were the same ones that had been identified earlier as "magnet" hospitals—those able to attract and retain nurses. A closer study revealed that they shared a similar organizational culture: one that valued social justice, consultation across levels, decentralized decision making and self-governance, flexible scheduling, and learning (Maunder et al. 2008).

Crisis has the effect of creating disruption at the institutional and problem domain levels, and at such times, if innovative alternatives are sufficiently well developed, the system can tip. One example comes from northeastern Honduras, where a climate related disaster, Hurricane Mitch, provided an opportunity for innovation in land management that led to improved well being of those affected (McSweeney and Coomes 2011). Interestingly, this opportunity was not provided by the aid organizations who were brought into manage the crisis, but rather on a household by household basis—almost "virally"—resulting in a shift to a more equitable land distribution, protected forests, and a community well positioned to cope with comparable flooding 10 years later (ibid p. 5203). Innovation was facilitated by the ability to "tap into collective social memories" (ibid p. 5205). The study revealed that the interventions of aid organizations in the local economy before Hurricane Mitch had actually heightened the community's vulnerability. "Future interventions," it was argued, "should foster local capacities for endogenous institutional change to enhance community resilience to climate shocks" (ibid, p. 5203).

These examples point to the importance of engaging bottom-up responses for timely and effective innovation. This requires that attention be paid to nurturing cultural norms of learning and memory. Top-down only responses to crisis often miss the opportunity for learning and innovation because of the emphasis on speed, and on avoiding blame (Walker and Westley 2011). Innovation occurs most readily in contexts where experimentation and exploration are encouraged and where innovative ideas, projects, designs, processes are connected to the institutional resources and opportunities that can give them broad impact and durability. To this end, agency, in the form of social, political, and institutional entrepreneurship, is vital.

Connecting the Two: the Role of Agency in Transformation

Systemic innovation strategies are fundamentally different from regular innovation strategies in that they are founded on notions of complexity, ambiguity, and diversity. They cannot depend purely on market forces, nor can they be deliberately planned. However, agency clearly plays a role at each stage of the process. Key persons can play pivotal roles in such learning processes including providing leadership, building trust, developing visions, and sense-making (Westley 2002; Olsson et al. 2004; Huitema and Meijerink 2009; Gutiérrez et al. 2011). These individuals can be important brokers for connecting people and networks (Bebbington 1997; Crona 2006; Ernstson et al. 2010) and also play a key role as nodes in learning networks (Manring 2007).

Institutional entrepreneurs and their networks may work simultaneously at building innovation niches into innovation regimes and at destabilizing the dominant landscape and regime to secure the required resources. At the broader institutional or landscape level, they act to "nibble" at the resilience of the dominant system, seeking opportunities in the market, the political/policy sphere and the cultural sphere, where resources can be redirected to the emerging innovation niche/regime and where elements supportive of the new regime can be inserted (see Fig. 4). Meanwhile, they nurture innovative alternatives, through sensemaking, building, and brokering partnerships between unusual suspects, selling the innovations to secure resources and creating disturbances in existing regimes and landscapes (Westley 2002; Olsson et al. 2004; Westley et al. 2006).

In this context, scholars have focused on the role of shadow networks, informal networks that work both outside and within the dominant system to develop alternatives that can potentially replace the dominant regime if and when the right opportunity occurs (Gunderson 1999; Olsson et al. 2006; Westley and Vredenburg 1997). Shadow networks are incubators for new ideas and approaches, for example for governing and managing social-ecological systems. Pelling et al. (2008) discuss the role of shadow spaces and organizations in fostering innovation and experimentation for social learning and adaptation to climate change. For example, regime change has become an issue in Hungary following repeated failures of conventional management policies to handle a series of floods on the Tisza River starting in 1997 (Sendzimir et al. 2008). A "shadow network" of activists and academics has emerged

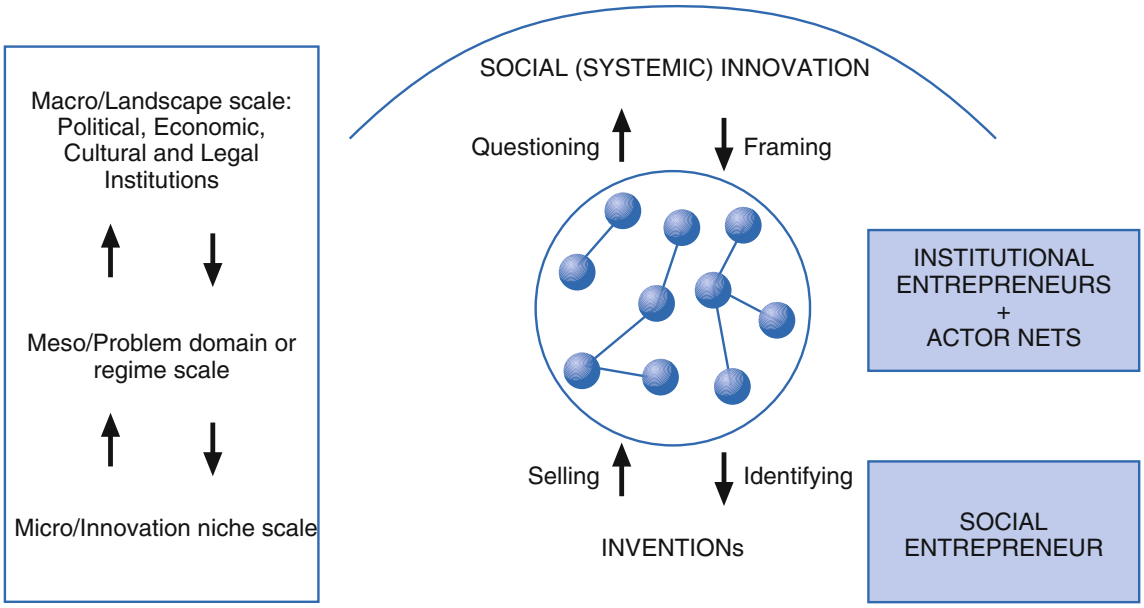

Fig. 4 Shifting resilience. While much attention is paid to preventing critical transitions that tip a system into an undesirable basin of attraction, institutional entrepreneurs are often doing the reverse: attempting to tip a dominant system into a more desirable or innovative basin of attraction

to point out how current river management appears trapped in a hopeless downward spiral of coping reactions that never build enough momentum to adapt and improve the situation. Increasing public participation catalyzed by the shadow network pushed the water policy debate toward more experimentation with alternatives, but implementation appears stalled. Here, the importance of a champion to sustain dialog until learning is enshrined in policy becomes evident.

An example can be drawn from the case of the Great Bear Rain Forest in British Columbia, Canada, where a network of institutional entrepreneurs worked simultaneously to: (a) destabilize the global market for old growth forest products and (b) challenge the government control of tracks of pristine wilderness through native land claims in Canadian courts; (c) convene stakeholders at local and provincial levels in negotiation and framing exercises, that also involved personal commitment to changed perceptions of the other actors; (d) broker agreements around clusters of innovative ideas; (e) sell those ideas to government and economic decision makers (Tjörnbo et al. 2010). The success of the work of institutional entrepreneurs is often dependent on timing: the occurrence of exogenous shocks, the availability of resources, the synchronicity with other trends or transitions occurring in the system. Skill, however, is also a key, including the capacity to anticipate when an opportunity or shock will occur. For example, Gelcich et al. (2010) describe how a new governance approach for marine resources emerged in the late 1980's in Chile at a time of marine resource crisis and political turbulence. The resource crisis triggered a few collaboration initiatives between fishermen and scientists in informal networks to start solving problems together and experimenting with new ecosystem management approaches. Political turbulence in the late 1980's provided a window of opportunity for fishermen to organize, scale up the innovation, and influence the new national fishery legislation and institutionalization of a new governance system for marine coastal resources in Chile (Fig. 5).

Social Media and Design Thinking: Two Promising Process Innovations

We need to understand how particular narratives give rise to certain dominant innovation pathways shaped by powerful interests, often with substantial financial and institutional backing. These are the "motorways" that direct current mainstream environment and development efforts and guide investments in agricultural science and technology. But these dominant pathways can often obscure or even overrun alternatives, the less-travelled "byways", "shadow tracks", or innovation regimes that define and respond to different sets of goals, values, and forms of knowledge, presenting alternatives to mainstream strategies for dealing with complex and dynamic social, ecological, and technological change and responding to shocks and stresses (Leach et al. 2010).

Tapping these "shadow tracks" then becomes a key challenge to governance, especially because traditional, expert-driven, centralized, and top-down approaches to problem solving are not nimble enough to effectively address convergent, nonlinear, and rapidly changing global

Fig. 5 Boats of a coastal fishing cove, or "caleta" involved in marine adaptive governance, Chile (photo Carl Folke)

problems characterized by high uncertainty. What this suggests is that we need to bring together and apply to these problems as many different ideas—and as many different heads—as possible to trigger real transformations toward global sustainability. Here is where emerging social media and associated advances in information and communication technologies can play a role. Because of its distributed nature, the Internet can make possible the rapid decentralized innovation our world urgently needs. It can help generate financial and political support for safe-fail experiments in communities around the world, using diverse technologies, organizations, and ideas.

This capacity cannot be taken for granted however. We are already experiencing severe sustainability challenges facilitated by rapid information technological change. Examples here include not only rapid online coordination aiming to undermine the authority of climate science as illustrated all to clearly during "Climategate", and hackers breaking into carbon market databases, but also the acceleration of the destruction of natural resources. This last concern was raised during the last meeting of the Convention on International Trade in Endangered Species (CITES) in 2010, where the case of Internet trade with threatened species was widely debated.

This calls for an explicit approach to direct the decentralized power of the Internet in ways that contribute to transformations toward sustainability. Scientists have found that all complex systems that are highly adaptive, like markets, tend to share certain features. First of all, the individual elements that make up the systems, such as companies in a market economy are extraordinarily diverse. Second, the power to make decisions and solve problems is not centralized in one place or thing; instead, it is distributed across the system's elements. The elements are then linked in a loose network that allows them to exchange information about what works and what does not. Often in a market economy, for example, several companies will be working at the same time to solve different parts of a shared problem, and important information about solutions will flow between them. Third, highly adaptive

systems are unstable enough to create unexpected innovations but orderly enough to learn from their failures and successes. Systems with these three features stimulate constant experimentation, and they generate a variety of problem-solving strategies.

The Internet and its subsystem, the World Wide Web, exhibit exactly these features. So, they could be the foundation for rapid problem solving and "knowledge generation" on a planetary scale; for a new generation of ecological monitoring systems (Galaz et al. 2010); for more effective multinational scientific collaboration (The Royal Society 2011); for polycentric experiments that increase social-ecological resilience; and for radically new forms of democratic decision-making. Most fundamentally, however, it can facilitate the conversation we must have among ourselves to identify and realize innovative approaches that support planetary stewardship and help us stay within critical planetary boundaries.

To date, though, open-source approaches have been applied to solving technical problems like the creation of complex software, large databases, or online encyclopedias. Now, we urgently need to explore if we can use this kind of approach—and the culture of voluntarism that underpins it—to address our bedeviling social, political, and environmental problems like climate change. Research and experimentation on such innovation platforms as crowd thinking and design thinking are underway and hold promise for accelerating social innovation that addresses complex problems such as environmental issues (Rockefeller Foundation 2008; Brown 2009). Positive examples here include Internet based micro-finance initiatives such as Kiva.org; knowledge sharing platforms for climate adaptation and water and sanitation innovations (e.g., WeAdapt 2011; Akvo 2011) and problem solving virtual platforms such as the MIT Center Collective Intelligence project CoLab, Internet-based approaches to assist the emergence of innovative ideas (e.g., InnoCentive and Environmental Defense Fund Eco-Challenge Series). Examples also point to the convening and mobilizing power of social media. With the help of the advances in information and communication technologies including satellite technologies, social mobilization has taken place around efforts to curb both illegal deforestation and surprising outbreaks of large-scale forest fires in the Amazon (Foster Brown 2006), the illegal and unreported fishing in Antarctica (Österblom et al. 2010).

While, recognizing that open-source methods cannot give us clear and final solutions to problems that are ultimately rooted in politics, they are still a powerful way to develop scenarios and experiment with ideas. If these methods are coupled with the skills and capacity to engage in trans-disciplinary, cross-sector problem solving, to design processes to sustain knowledge integration and behavioral change, they can help us build worldwide communities of like-minded people who, in the course of working together on tasks, become bound together by trust and by shared values and understandings. The growing interest on the part of governments, universities, and think tanks in Change Labs is promising. Such change labs offer a place for creative, cross-sector and cross-disciplinary decision-making and innovation. The process is supported by careful design and facilitation and is resourced by research geared to the decision maker's needs. The focus is on those "wicked problems" that seem insoluble, and reconciling seemingly antithetical elements such as the need to grow the economy and to maintain environmental services, or to maximize both short term profitability and long-term sustainability (Banerjee 2008; Bason 2011) (Fig. 6).

CONCLUSIONS

Innovation is a double-edged sword. Much of the economic and population growth that has compromised ecosystem services has been driven by technological innovation. However, we propose that the human capacity for innovation can equally be used as a positive force for supporting transformations toward global sustainability; indeed that it is essential. The challenge is to use the planetary opportunity to direct innovation capacity into a sustainability pathway.

There is no deficiency of social and technological innovations in the world. In fact, the tremendous expansion of humanity and the great acceleration into the Anthropocene are a reflection of an amazing innovation capacity, supported by easily accessible and abundant energy sources, predominantly fossil fuels. However, much of this innovation has occurred without reference to ecological integrity, or complex system interactions. It is also innovation that has been insufficiently tuned to the challenges of poverty alleviation, human rights, social justice, and human well being.

A key challenge now is to use this innovative capacity to change the current unsustainable trajectories and support transformations toward global sustainability. The barriers originate, in part, from the cognitive limits of human ingenuity in the face of complex dynamics, and the associated failure to anticipate unexpected consequences of innovation. Lock-ins and lags are also due to the path-dependent nature of technology, the incentives and regulations that govern private sector innovations and the self-referent nature of the institutions governing society, the environment, and technology.

Major ongoing attempts to transform include transitions toward new energy sources and integrated approaches to management and governance of ecosystems services.

Fig. 6 There is no deficiency of social and technological innovations, but innovation capacity needs to be redirected supporting transformations that reconnect people to the biosphere (photo Carl Folke)

These processes are supported by numerous initiatives around the world, clean energy, particularly for the developing world, conservation economies, biosphere reserves, eco-agriculture, and ecosystem-based fisheries management. To support 9×10^9 people without transgressing critical planetary boundaries, efforts to diffuse and scale the most promising innovations must be accelerated. This requires the transformation of the institutions that shape our cultural, political, and economic transactions—in short, shift our governance processes from those that do not privilege systemic innovation to those that do.

Incentives and enabling conditions are needed to stimulate the emergence of technical and social innovations that help reconnect to the biosphere and respect interacting planetary boundaries. Innovation challenges, new investment funds, seed money, and other incentives developed by state and non-state actors at local, national, and regional levels are helpful. So too are attention to framing alternatives, and creating policy and legal conditions that promote such innovation. This includes stimulating viable, alternative pathways, or "shadow tracks", and harnessing the creativity inherent in innovation niches to these broader sustainability goals. Supporting institutional entrepreneurs who can identify and promote transformative innovations and connecting them to the necessary capital—social, financial, and cultural will help to ensure institutional

impact, durability, and scale. Transformation will be as much a matter of social as technical innovation.

A more connected global society has the means to quickly respond to change and stimulate innovations on a planetary scale. Expert-driven, centralized, and top-down approaches to problem solving are not nimble enough to effectively address global challenges characterized by high levels of complexity and uncertainty. Nor are traditional, disciplinary-based research approaches. New forms of knowledge integration and generation that support planetary stewardship are required, capable of integrating a much richer diversity of ideas and viewpoints and of bringing action and research into closer proximity.

Social media and associated advances in information and communication technologies can play a significant role in providing platforms for the stimulation and integration of the ideas as well as mobilizing collective action at key moments of opportunity. Investment in "policy laboratories" or "Change Labs" can create the conditions for successful integration of different perspectives and knowledge sets, facilitating breakthroughs in complex problem domains through the use of sophisticated process design, and "beta testing" alternative, more sustainable policy and management options that can be ready when, for example, a crisis opens up a window of opportunity for transformative change. Financial and political support is required to create such spaces for safe-fail experiments in communities worldwide.

Acknowledgments We acknowledge support from Stiftelsen Futura, Kjell and Märta Beijer Foundation, Formas, and Mistra through a core grant to the Stockholm Resilience Centre, a cross-faculty research centre at Stockholm University.

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