AMBIO (2011) 40:719–738
DOI 10.1007/s13280-011-0184-y

INVITED PAPER

Reconnecting to the Biosphere

Carl Folke, Åsa Jansson, Johan Rockström, Per Olsson, Stephen R. Carpenter, F. Stuart Chapin III, Anne-Sophie Crépin, Gretchen Daily, Kjell Danell, Jonas Ebbesson, Thomas Elmqvist, Victor Galaz, Fredrik Moberg, Måns Nilsson, Henrik Österblom, Elinor Ostrom, Åsa Persson, Garry Peterson, Stephen Polasky, Will Steffen, Brian Walker, Frances Westley

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

Abstract Humanity has emerged as a major force in the operation of the biosphere, with a significant imprint on the Earth System, challenging social–ecological resilience. This new situation calls for a fundamental shift in perspectives, world views, and institutions. Human development and progress must be reconnected to the capacity of the biosphere and essential ecosystem services to be sustained. Governance challenges include a highly interconnected and faster world, cascading social–ecological interactions and planetary boundaries that create vulnerabilities but also opportunities for social–ecological change and transformation. Tipping points and thresholds highlight the importance of understanding and managing resilience. New modes of flexible governance are emerging. A central challenge is to reconnect these efforts to the changing preconditions for societal development as active stewards of the Earth System. We suggest that the Millennium Development Goals need to be reframed in such a planetary stewardship context combined with a call for a new social contract on global sustainability. The ongoing mind shift in human relations with Earth and its boundaries provides exciting opportunities for societal development in collaboration with the biosphere—a global sustainability agenda for humanity.

Keywords Social–ecological systems · Resilience · Ecosystem services · Natural capital · Adaptive governance · Planetary stewardship

INTRODUCTION

People and societies are integrated parts of the biosphere,[1] depending on its functioning and life-support while also shaping it globally, with geological imprints in the Earth System (Steffen et al. 2011). The issue at stake is broader than climate change. It is about a whole spectrum of global environmental changes that interplay with interdependent and rapidly globalizing human societies. A key challenge for humanity in this new situation is to understand its role in the Earth System, start accounting for and governing natural capital and actively shape development in tune with the biosphere (Jansson et al. 1994; Rockström et al. 2009). This is a new situation and it calls for new perspectives and paradigms on human development and progress—reconnecting to the biosphere and becoming active stewards of the Earth System as a whole.

During the last couple of generations, we have witnessed an amazing expansion of human activities into a converging globalized society, enhancing the material standard of living for a large part of people on earth, and despite still many in destitution the gaps between rich and poor are closing in regions of the world (Rosling 2010). The expansion in particular since the 1950s, which predominantly benefitted the industrialized world, has pushed humanity into a new geological era, the Anthropocene, and generated the bulk of the global environmental changes with potential thresholds and tipping points, currently challenging the future wellbeing of the human population on Earth (Steffen et al. 2007; Rockström et al. 2009).

Now, new accelerations are occurring. The majority of the world's population has started to move decisively out of poverty with a rise of an affluent middle class aiming for material growth and increased income in a rapidly urbanizing world—an environmental challenge as well as equity

[1] The biosphere is the global ecological system integrating all living beings and their relationships, including their interaction with the elements of the lithosphere, hydrosphere, atmosphere and cryosphere (the Earth's surface where water is in solid form, including the poles and permafrost regions).

challenges of momentous scale (Leach et al. 2010). Simultaneously, information technology, nano-technology and molecular revolution are accelerating with unknown potentials, while the speed of connectivity and feedbacks of globalization create new complex dynamics across levels and domains with often surprising outcomes. In addition, international institutions are becoming increasingly complex and fragmented through the evolution of a suite of public, private and hybrid forms of transnational collaborations (Andonova and Mitchell 2010), presenting new governance challenges for global sustainability.

Current perspectives and worldviews mentally disconnect human progress and economic growth from the biosphere (Arrow et al. 1995; O'Brien 2009) and the life-supporting environment,[2] if not simply ignored, has become external to society with people and nature treated as two separate entities. We still seldom account for changes in the capacity of natural capital to sustain human wellbeing in measurements of progress like GDP or the human development index and tend to treat the environment as a sector in policy and decision making.

But things are changing. For example, freshwater was earlier largely viewed as a natural resource extracted from rivers and groundwater for households, industry, and irrigation. Now, there is a shift in perspective reconnecting water governance to the life-supporting ecosystems, emphasizing the role of water as the bloodstream of the biosphere with people as embedded parts (Falkenmark and Folke 2003; Hoff 2009; Fig. 1). New approaches linking water and ecosystems services, like adaptive water governance, are emerging (Gordon et al. 2008; Raudsepp-Hearne et al. 2010; Pahl-Wostl et al. 2011). Similar trends are seen in shifts toward ecosystem-based adaptive governance of dynamic landscapes and seascapes incorporating forestry, agriculture and fisheries.

Societies are not only interconnected globally through political, economic, and technical systems, but also through the Earth's biophysical life-support systems. Globalizing human–environment interactions are characterized by increasing connectivity, speed, mobility, and scale (Young et al. 2006). For example, shrimps farmed in ponds in Thailand for export to global markets, are fed with fish meal derived from marine ecosystems worldwide (Fig. 2) (Deutsch et al. 2007). Numerous similar interactions play out in all corners of the world. The urbanized global society, which accounts for >50% of the world population, depends on the capacity of ecosystems of all kinds worldwide to support urban life with essential ecosystem services (Folke et al. 1997; Grimm et al. 2008), even though people may not perceive this support or have preferences for it.

Human action alters ecosystem support not only locally and regionally but also globally. Increases in connectivity, speed, and scale may enhance the capacity of societies to adapt and transform with changing circumstances. However, if globalization operates as if disconnected from the biosphere it may undermine the capacity of the life-supporting ecosystems to sustain such adaptations and transformations. Shifting from managing natural resources one by one and treating the environment as an externality to stewardship of interdependent social–ecological systems is a prerequisite for long-term human wellbeing (Berkes and Folke 1998; Ostrom 2009; Chapin et al. 2011).

In a globalized society, there are no ecosystems without people and no people that do not depend on ecosystem functioning. They are intertwined and thus, ecosystem services are generated by social–ecological systems. Social–ecological systems are dynamic and connected from the local to the global, in complex webs of interactions subject to gradual and abrupt changes. Dynamic and complex social–ecological systems require strategies that build resilience rather than attempting to control for optimal production and short-term gain in environments assumed to be relatively stable. The shift from people and nature as separated parts to interdependent social–ecological systems provides exciting opportunities for societal development in tune with the biosphere; a global sustainability agenda for humanity.

In this article, we focus on the necessity and challenge of reconnecting humanity to the biosphere. It is argued that this is a fundamental prerequisite in the search of planetary opportunities that meet both global sustainability criteria and human development needs. The first section is about understanding the dynamics of natural capital and social–ecological resilience in a globalized world with multiple links and feedbacks. We present attempts to account for natural capital in economic development and discuss governance challenges of social–ecological systems from the local to the global.

NATURAL CAPITAL AND SOCIAL–ECOLOGICAL RESILIENCE

The UN Millennium Ecosystem Assessment (MA 2005), the first scientific global stocktaking of the world's ecosystem services, helped clarify the significance of natural capital and ecosystem services for human wellbeing. The assessment also helped connect the climate issue to ecosystems services. For example, terrestrial and marine ecosystems have over the

[2] The life-supporting environment has been defined as "that part of the earth that provides the physiological necessities of life, namely food and other energy, mineral nutrients, air and water", and the life-support system as "the functional term for the environment, organisms, processes, and resources interacting to provide these physical necessities" (Odum 1989).

Fig. 1 Reconnecting to the biosphere, Stockholm archipelago, Sweden (photo: Carl Folke)

past 150 years provided an immense ecosystem service to humanity by absorbing ~50% of the global carbon dioxide emissions (Canadell et al. 2007).

Resilience is a conceptual framework for understanding how persistence and transformation coexist in living systems, including human societies. The existence of tipping points and thresholds highlights the importance of understanding and managing resilience. Continuation of civilization requires us to stay within certain thresholds; some are moral imperatives and others are biogeophysical boundaries (Rockström et al. 2009). Yet coping with past problems often creates dysfunctional systems. To meet coming challenges requires transformations of world views, institutions, approaches, and methods. The elements of transformation exist, but are not yet dominant in society (Westley et al. 2011).

Resilience is about dynamic and complex systems[3] and is here defined 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 (Folke et al. 2010). The resilience lens has been applied to understand social–ecological dynamics in different parts of the world (Walker et al. 2006; Chapin et al. 2009), in developed and developing regions, in traditional societies, among vulnerable peoples or for combating poverty, for example, in shifting from dryland poverty traps into improved livelihoods (Enfors and Gordon 2008), in dealing with disasters among rural communities in developing countries (McSweeney and Coomes 2011), in growing the wealth of the poor (WRI 2008) or in livelihood and land-use choices among farmers in Latin America in relation to the sensitivity to future market and environmental shocks (Eakin and Wehbe 2009).

[3] Complex systems are characterized by multiple pathways of development (multiple states or basins of attraction), interacting periods of gradual and rapid change, feedbacks and non-linear dynamics, thresholds, tipping points and shifts (transitions) between pathways, and how such dynamics interacts across temporal and spatial scales.

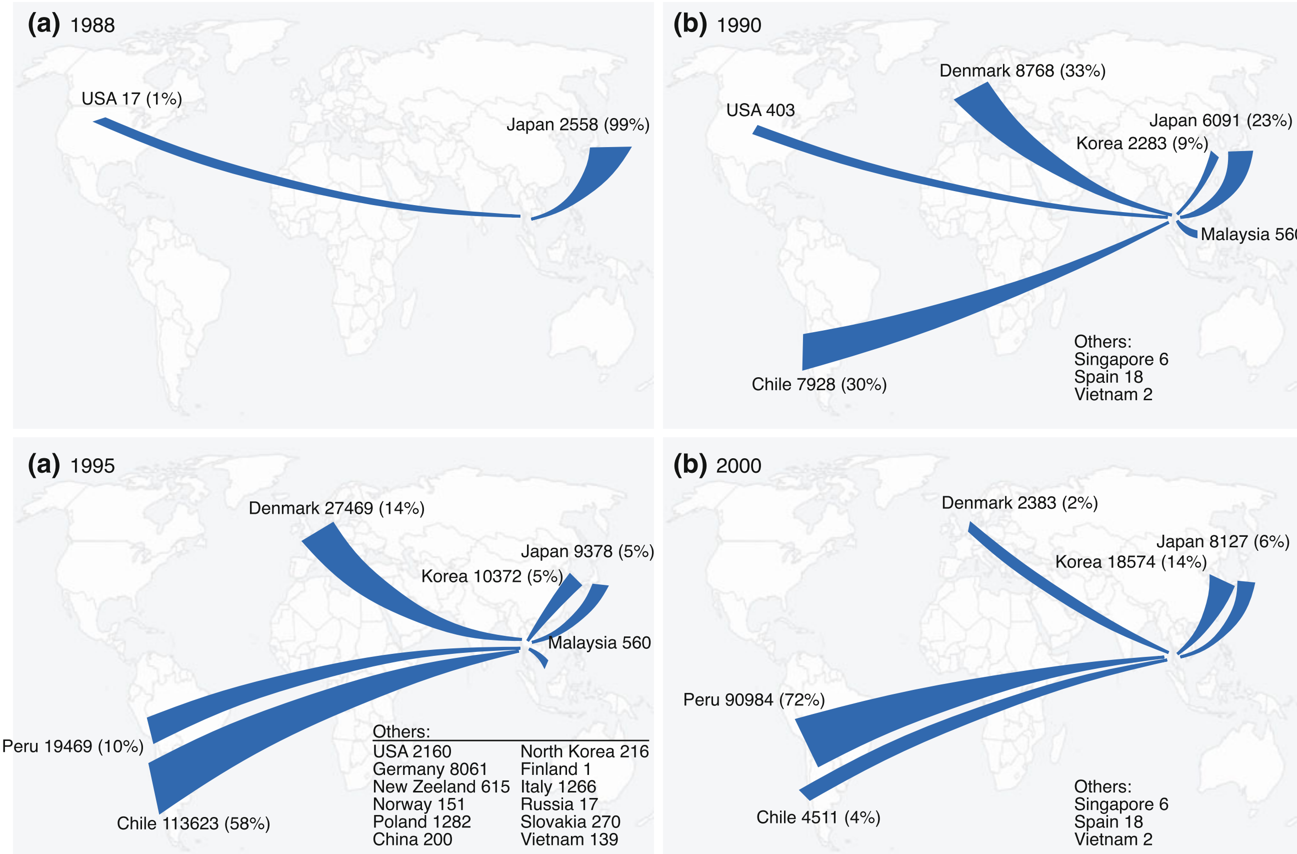

Fig. 2 Sources of fishmeal imported to Thailand 1988, 1990, 1995, and 2000. Fishmeal amounts are metric tonnes and the numbers in parentheses are the percentage of total imports. Fishmeal is used in shrimp farming in Thailand (modified from Deutsch et al. 2007)

Resilience, Traps, and Regime Shifts

The capacity of natural capital to generate ecosystem services interacts dynamically with disturbance, regeneration, and reorganization. In resilient systems, disturbance opens up opportunity for regeneration and renewal, in ways that depend on the influences from states and dynamics occurring at larger and smaller scales. In systems with low resilience, the same disturbance may shift the system into another state (Scheffer 2009). In some cases, the transition is sharp and dramatic. In others, the transition may be less dramatic, even though the dynamics of the system has shifted from one attractor to another (Walker and Meyers 2004). Often, passive monitoring-and-control systems are unable to learn as fast as the thresholds move. In such situations there is great advantage to adopting strategies that increase the speed of learning, allow rapid feedback to decisions to shift course to avoid damaging shifts, and have the ability to adjust should regime shifts occur (Scheffer et al. 2009; Polasky et al. 2011a). Understanding the potential occurrence and consequences of ‘regime shifts’ in complex dynamical systems ranging from ecosystems to financial markets and climate are an area of active research (Biggs et al. 2009; Scheffer et al. 2009).

Human actions are often viewed as external drivers of ecosystem dynamics; examples include fishing, water extracting, and polluting. Through such a lens the manager is an external intervener in ecosystem resilience. However, many of the serious, recurring problems in natural resource use and environmental management stem precisely from the lack of recognition that ecosystems and the social systems that use and depend on them are inextricably linked. It is the feedback loops among them, as interdependent social–ecological systems, that determine their overall dynamics and sustainability (Folke et al. 2010).

The Maine lobster fishery in USA (Fig. 3), for example, has rightly been described as an exemplary case of collective action, connecting local fishermen to the State of Maine and global markets (Wilson et al. 2007). In contrast to other fisheries in the Gulf of Maine, this economically lucrative activity has not overexploited the lobster upon which its successful development is based. But, if the analysis is expanded from the single lobster resource to the broader Gulf of Maine social–ecological system it becomes

Fig. 3 Cape Cod lobster, Massachusetts, USA (photo: Carl Folke)

clear that the success is not only a consequence of wise stewardship of one species. Rather, historical overexploitation of fish species has depleted the lobster predators from the Gulf and allowed the lobster population to literally explode into a widespread monoculture in the coastal waters of Maine. Monocultures are known to be susceptible to shocks, a symptom of their low resilience. In southern New England, likely as a consequence of climate change, the lobster fishery has been hit by a disease with about 70% decline in the lobster population (Steneck et al. 2011). Thus, people often inadvertently create social–ecological vulnerability as they adapt and transition from one technology or resource opportunity to another (Holling et al. 1998; Ostrom 2007).

Strategies for successful economic development that ignore the broader ecosystem and its dynamics may push people into vulnerable social–ecological dynamics and persistent undesirable states such as poverty or rigidity traps (Bowles et al. 2006; Scheffer 2009). Hence, understanding and governing the social, legal, and economic aspects of resource management alone are insufficient for sustainable outcomes unless coupled with understanding and active management of ecosystem dynamics.

In the Goulburn-Broken catchment in the Murray Darling Basin, Australia, dryland cropping, grazing, irrigated dairy and fruit production is widespread. The catchment produces one quarter of the State of Victoria's export earnings. At first glance, economically lucrative activities seem to be thriving. But widespread clearing of native vegetation and high levels of water use for irrigation have resulted in water tables rising to the soil surface, creating severe salinization problems—so severe that the region faces serious social–ecological thresholds with possible knock-on effects between them. Crossing such thresholds may result in irreversible changes in the region. Transforming away from the current situation requires people to change deep values and identity (Walker et al. 2009a).

European fisheries seem to be in a similar trap, reinforced by multiple social–ecological feedback loops. Aggravated by subsidies, technological development has produced overcapacity, creating political pressure for short-term decision-making and unsustainable quotas.

Stocks fished at unsustainable levels produce less, leaving less fish available to catch, with poor economic performance of the fishing fleet, forcing some actors to resort to fishing illegally, further reducing stock status and making quantitative stock assessments difficult and creating uncertainty around the scientific forecasts that underpin political decisions. The legitimacy of science is undermined and low transparency in the politicized decision-making process and lack of legitimacy of decisions further reduce incentives for compliance. The result is a political pressure for subsidies and higher quotas, reinforcing the existing overcapacity, digging the trap deeper (Österblom et al. 2011).

The examples presented above illustrate that social–ecological systems may find themselves trapped in undesired basins of attraction that become so wide and deep that reconfiguration of the existing basin becomes extremely difficult and movement out of it painful. Social and ecological capacity is needed to move out of such undesired basins (Westley et al. 2011). We call this challenge transformability, that is, the capacity to create untried beginnings from which to evolve a new way of living when existing ecological, economic, and social conditions make the current system untenable (Chapin et al. 2010; Folke et al. 2010).

Cross-Scale Linkages and Feedbacks

In the globalized social–ecological system, intricate cross-scale interactions play out in novel ways (Lambin et al. 2003; Holling 2004; Adger et al. 2009; Galaz et al. 2010). Urban fads, life-style changes, emergent markets, flows of resources, people, and information create new cross-scale linkages and feedbacks that increasingly connect distant peoples and places and shape the capacity of the biosphere to sustain human wellbeing in new ways.

For example, in fisheries a new dynamics has arisen with a globalized world. New markets can develop so rapidly that the speed of resource exploitation often overwhelms the capacity of local institutions to respond. Technological developments have made it possible for distant water fleets and mobile traders to operate like roving bandits, that is mobile agents that move on to other, unprotected resources when the first has been depleted. The rapid emergence of specialized export markets for hitherto unexploited stocks is often a surprise to managers and serial depletion of local stocks is masked by spatial shifts in exploitation (Berkes et al. 2006).

The widespread expansion of palm oil plantations, a current example, is predominantly taking place in tropical regions in South and Central America, West Africa and especially in Malaysia and Indonesia (Fitzherbert et al. 2008). The oil is a relatively cheap biofuel (whether as palm biodiesel or for direct burning), with price advantages and particular properties for food and feed. In Indonesian Borneo (Kalimantan), concession-based timber extraction, oil palm plantation establishment (Fig. 4), and weak institutions have resulted in highly fragmented and degraded forests (Curran et al. 2004). Fragmentation and land cover change is predominantly driven by global market demand for palm oil and tropical timber.

The dynamic development of the Bornean rainforest is a telling example of the interactions between disturbance events, regeneration, resilience, and vulnerability. There, El Niño-induced droughts trigger mast reproduction among rainforest trees, and though the rainforest fauna make use of it the amount of reproduction is such that new trees successfully establish. Thereby, El Niño serves as trigger for regenerating the rainforest and its biodiversity. In recent decades, however, the global market demand has shifted the Borneo landscape into rainforest ecosystem fragments separated by large-scale monoculture plantations. In this new situation, El Niño events disrupt fruiting of the rain forest trees, interrupt wildlife reproductive cycles, erode the basis for rural livelihoods, and trigger droughts and wildfires (Curran et al. 2004). Page et al. (2002) estimated that the widespread El Niño-related wildfires of Borneo in 1997 released between 0.81 and 2.57 Gt of carbon to the atmosphere, equivalent to 13–40% of the mean annual global carbon emissions from fossil fuels.

Hence, globalized economic drivers, impacting places with weak and fragmented institutions can turn disturbance events like El Niño from regenerative forces into destructive forces. In the Bornean landscape, the change from a biodiversity-rich multifunctional tropical rainforest to a simplified palm oil landscape shifted Borneo from a carbon sink to a carbon source. The example illustrates cross-scale globally connected links among emergent markets, biodiversity, land-use change and climate feedbacks. Other important cross-scale linkages include changes in variability of rainfall patterns that will most likely expose regions to changes in frequencies, magnitude and durations of droughts, fires, storms, floods, and other shocks and surprises, affecting for example, food production, trade and possibly sociopolitical stability (Fraser and Rimas 2011). Global time–space compression, in which actions taken in one place may have direct and immediate consequences at other places worldwide are becoming more common and increasingly result in "teleconnected vulnerabilities" (Adger et al. 2009).

In a globally interconnected world where everyone is in everyone-else's backyard, drivers of change like rising human numbers, urbanization, migration patterns, emerging markets, diffusion of new technologies or social innovations may combine with shocks like ecological crises, rapid shifts in fuel prices, and volatile financial markets. Such

Fig. 4 Fruit of the oil palm *Elaeis* (photo: Carl Folke)

new interactions present a range of institutional and political leadership challenges, which have been insufficiently elaborated by either crisis management researchers or institutional scholars (Galaz et al. 2010) (Fig. 5). The above examples draw attention to nonlinear changes, tipping points and thresholds at local to regional scales, with global links and feedbacks, exposing vulnerabilities, challenges, and also opportunities for social–ecological change.

A major governance challenge in this context is to strengthen resilience of social–ecological systems, whether in urban or rural landscapes or seascapes, to deal with such global links and feedbacks and to use them as opportunities for reconnecting societal developments to the biosphere. The challenge of reconnecting to the biosphere should be central in efforts addressing vulnerable peoples and places, food insecurity, poverty, sustainable livelihoods, inequality, power relations, conflicts, the rule of law, political (in)stability and democratization processes.

At the core of the global sustainability challenge is extending the human favorable period of relative stability

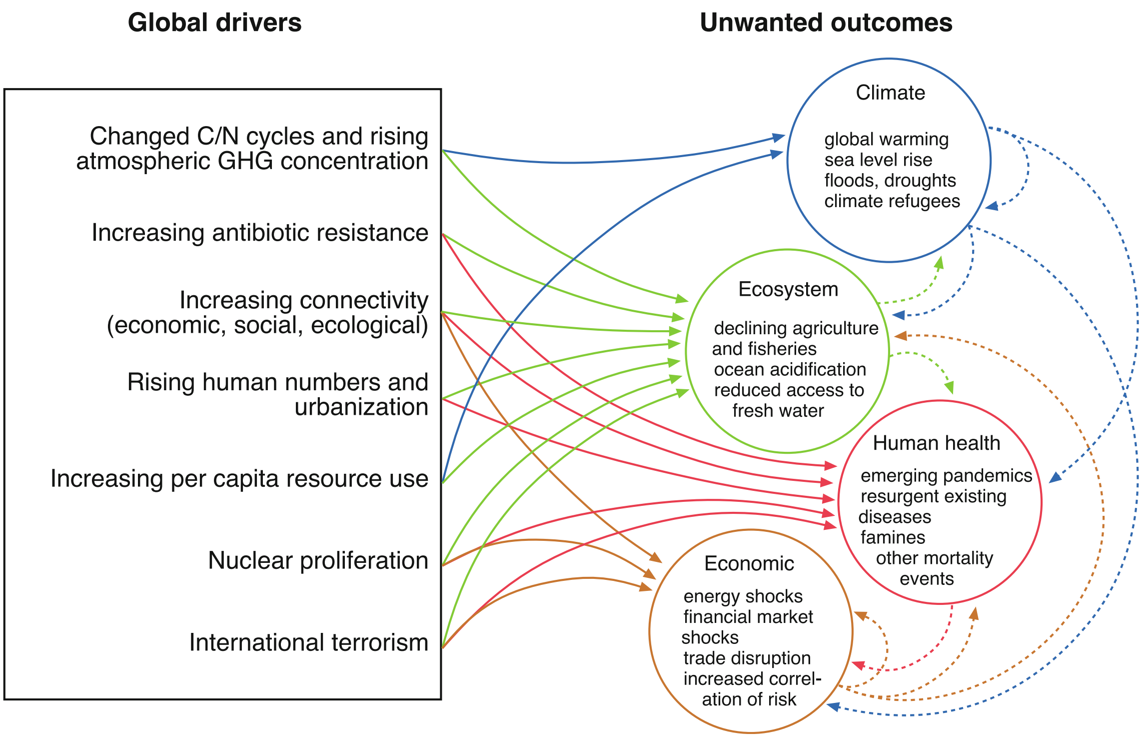

Fig. 5 Examples of interactions between global drivers, shocks and economic, climate, health, and ecosystem changes. The latter are often treated separately but are increasingly interdependent (Crépin et al. 2011a; modified from Walker et al. 2009b)

of the last 10 000 years that has allowed our species to flourish (Steffen et al. 2011), representing a globally desirable social–ecological resilience state (Folke et al. 2010). It will require the ability to govern for persistence with change to avoid tipping into a new undesirable Earth System state. It will require transformations at local and regional scales (Westley et al. 2011). A significant part of this challenge is to make the work of the biosphere visible in society, in human actions and in financial and economic transactions.

ACCOUNTING FOR NATURAL CAPITAL

The role of natural capital in generating ecosystem services for the operation of the economy is increasingly appreciated and interest in the valuation of ecosystem services is escalating in both research and policy.

Significant efforts including The Economics of Ecosystems and Biodiversity study (TEEB 2011), The Natural Capital project (Kareiva et al. 2011), diverse approaches of payments for ecosystem services (Wunder et al. 2008), green accounting and inclusive wealth (e.g. Mäler et al. 2008), corporate ecosystem services reviews (e.g. Hanson et al. 2008) and several efforts to develop a green economy, which while often focusing on energy and climate challenges (e.g., Stern 2006) have lately expanded into broader biospheric approaches (UNEP 2011). Twenty-seven countries have decided to launch initiatives to include natural capital in their national accounting (see http://www.ens-newswire.com).

New policy innovations are underway that account for natural capital and resilience principles in decisions. These include incorporating economic values of ecosystem services into decision making, through incentives and price signals, payments for ecosystem services, reforming environmentally harmful subsidies, and introducing tax breaks for ecosystem stewardship (e.g. TEEB 2011). Other initiatives have focused on improving local or regional governance of ecosystem services. These innovations are one way to make evident the connection between the economy and the biosphere.

Major ecosystem service investments are being made in China (Box 1), and there are several other countries with major programs, such as water funds in Latin America, through which water consumers pay for upstream conservation and restoration of natural capital; land-use zoning around natural capital in Sumatra and seascape planning in Australia. The ability of most of these programs to actually improve natural capital has not been determined, but the diversity of efforts and approaches illustrates the attractiveness of enhancing natural capital.

BOX 1: NATURAL CAPITAL INVESTMENTS IN CHINA

Following severe droughts in 1997 and massive flooding in 1998, China has, over the current decade, started to implement ecosystem service investments through several national forestry and conservation initiatives, exceeding 700×10^9 yuan (about US\$$100 \times 10^9$) (Zhang et al. 2000; Liu et al. 2008). Over 120 million farmers (in over 30 million households) are directly involved in the programs. The larger and older of these initiatives are being rigorously evaluated to determine their biophysical and socioeconomic impacts and to improve their design and efficacy.

These initiatives have dual goals: to secure critical natural capital through targeted investments across landscapes and regions, and to alleviate poverty through targeted wealth transfers from coastal provinces to inland regions where many ecosystem services originate. The initiatives include two national payments for ecosystem services programs, the Natural Forest Conservation Program (NFCP) and the Grain to Green Program (GTGP), also called the Sloping Land Conversion Program or Farm to Forest Program, established in 1998 and 1999, respectively. Implementation was tested in a few provinces and then rapidly scaled to the entire country (Fig. 6).

The NFCP aims in the short term are to reduce timber harvesting from natural forests and to create alternative employment for traditional forest enterprises. The long-term goal (2010–2050) is to restore natural forests and meet domestic demand for timber in plantations. The GTGP complements the NFCP in focusing on China's largest source of soil erosion: farms on steep slopes. The GTGP aims to convert ca., 15 million ha from cropland on steep slopes back to forest and grassland. In addition, ca., 17 million ha of degraded, barren land are to be afforested. Under both programs, payments to villagers are made in the form of cash and grain subsidies and tax breaks, in exchange for specific activities required to transition to natural forest, forest plantation, and grassland (Liu et al. 2008).

China is also in the process of establishing a new network of "Ecosystem Function Conservation Areas" (EFCAs), specifically for ecosystem service provision. Their exact delineation is now being determined through quantitative ecosystem service mapping. They are expected to span ca., 25% of the country and all provinces (Ouyang and Zheng, personal communication). In addition, there are ecosystem service initiatives at sub-national levels, oriented around the provision of drinking water and flood protection (Bennett 2009).

Overall, social impacts of the programs are mixed and depend on the details of the financial incentives and property rights (Liu et al. 2008; Cao et al. 2009). In some places, payment levels and types are leading to improvements in economic measures of wellbeing whereas in others payments were insufficient to compensate for loss of income from shifting livelihoods (Liu et al. 2008).

Accounting for Resilience

Capturing values in complex social–ecological systems is not a simple task. Current approaches to valuation are generally about incremental change. Measurement of incremental values works best when the increments are small, so that a change in one service will have minimal feedbacks through the rest of the system. Such conditions are difficult to meet for many ecosystem services (Daily et al. 2000). The likelihood of shifts between states makes the task of finding accounting prices for natural capital difficult since they may change in discontinuous ways (Crépin et al. 2011b). This has motivated attempts to capture the concept of resilience in environmental accounting (Walker et al. 2010) and regime shifts in models of renewable resource exploitation (Polasky et al. 2011b).

The implications of a connected world where the economy and the biosphere are linked in complex ways have not been sufficiently addressed. The linkages between the economy and the biosphere have often focused on the economic impacts of climate change and the policy options available (Nordhaus and Boyer 2000), highlighting the importance of insurance against severe consequences versus incremental benefit-cost estimates (Stern 2006). But the role of the biosphere and global resilience in macro-economic models is not widespread. The potential economic impacts and the implications for macroeconomic policy of transgressing important planetary boundaries or of potential large scale regime shifts (Brock et al. 2011) and critical feedbacks between Earth System dynamics, ecosystems and economics need much more attention.

GOVERNANCE: RECONNECTING PEOPLE TO THE BIOSPHERE

Regardless of whether accounting and valuation are taken further as important tools for improving global sustainability, they need to be underpinned and complemented by

Fig. 6 Current distribution of the National Forest Conservation Program (NFCP) and the Grain to Green Program (GTGP) in China, showing names of provinces, autonomous regions, and municipalities (adapted from Liu et al. 2008)

broader strategies for governance of global dynamics (Walker et al. 2009b). Such governance needs to enhance the fit between institutions and ecosystems (Ostrom 2009; Boyd and Folke 2011) and capture essential social–ecological links and feedbacks in adaptive and multilevel governance (Ostrom 2007, 2010).

Ecosystem-Based Management and Adaptive Governance

The focus of governance is slowly moving from conventional, sector-based resource management to more integrated approaches for managing landscapes and seascapes and the ecosystem services that they generate. These new modes emphasize that it is not just the resource but the capacity of natural capital to sustain it that requires monitoring, understanding and stewardship (Chapin et al. 2009). Ecosystem-based management for example, recognizes that people shape natural capital and its capacity to sustain resource flows in any ecosystem directly or indirectly, now and through history, from local groups to globalized urban dwellers (Kay et al. 1999; Waltner-Toews et al. 2003). Ecosystem-based management in any place operates in a global context and requires collaboration and collective action in much more complex institutional and actor settings than previously acknowledged in studies of local natural resource management institutions (Mahon et al. 2009; Galaz et al. 2008). Breaking robust institutions and moving toward integrated approaches might be very difficult. For example, marine zoning and shifts to ecosystem-based management in the United States have been severely constrained by inflexible institutions, lack of public support, and difficulties developing acceptable legislation (Crowder et al. 2006).

Despite these difficulties, new integrated management systems, like adaptive co-management of ecosystems are emerging and being institutionalized around the world (Gunderson and Light 2006; Armitage et al. 2007; Berkes 2009; Gunningham 2009; Cundill and Fabricius 2010). In Sweden, management of wildlife has developed into a multilevel co-management system, moving toward an increasingly adaptive mode to be able to deal with complex and highly fluctuating environmental conditions as well as changing social, economic, and political situations (Wennberg DiGasper 2006). Such management builds on the participation of a diverse set of interest groups operating at different scales, from local users, to municipalities, to regional and national organizations, and occasionally also international networks and bodies (Boyd 2008; Brondizio et al. 2009). For example, the UNESCO's Man and the Biosphere Program supports the creation of Biosphere Reserves as learning sites and "policy laboratories" for sustainable development (e.g., Matysek 2009; Schultz et al. 2011). The Program links global environmental governance with place-based ecosystem management and spans local-regional, national, and international scales.

Successful ecosystem-based management depends on adaptive governance systems that support such 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; Olsson et al. 2008; Berkes 2009; Bodin and Crona 2009). 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.

Enabling legislation and governmental policies such as UN Conventions, EU Directives, or national guidelines can act to support emergent and self-organizing processes instead of constraining them (Gunderson et al. 1995; Olsson and Galaz 2009), create bridging functions and frame creativity for adaptive governance. Literature on polycentric institutions is demonstrating that dynamic efficiency is enhanced by systems of governance that exist at multiple levels with some degree of autonomy complemented by modest overlaps in authority and capability (Ostrom 2010). A polycentric decision-making structure allows for testing of rules at different scales and aids resource users at multiple levels in the crafting of new institutions to cope with changing situations. However, a polycentric governance system may be hard to intentionally design and is rather the outcome of situations with 'multiple externalities', or benefits at multiple levels (local, national, regional, global) (Ostrom 2010). A global governance challenge is thus to identify such multiple externalities and ensure that action taken to internalize them at multiple levels strives toward the same objective.

Adaptive governance includes the ability to shift between decentralized and centralized governance modes, and between steering and self-organization. Even though self-organization and collaboration in polycentric settings hold a great potential, these require both institutional and economic support to be able to function effectively in the longer term (Lugten 2010). For example, any international attempt to address the challenges posed by the combined impacts of climate change, ocean acidification and rapid loss of biodiversity in marine ecosystems require not only cross-UN-organizational collaboration, but also explicit acknowledgements from existing multilateral environmental agreements (e.g. UNFCCC), as well as economic support, to be able to have an impact in local settings where other issues might be viewed as more urgent.

The emergence of a multilevel global adaptive governance system to curb the illegal and unregulated fisheries in Antarctic waters is a telling example. Illegal and unregulated fisheries have for decades challenged the international management of Antarctic fisheries (Ruckelhaus et al. 2008). In Antarctica, highly adaptive and globally operating actors carried out the illegal and unregulated fishery (Österblom et al. 2010). Effective international collaboration between states was initially hampered by the political sensitivity of the issue and a lack of political will for consensus decisions aimed at well-designed compliance mechanisms. Non-state actors (NGOs and the fishing industry) and their engagement in CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources) responsible for managing this fishery enabled the emergence of novel ways to address the problem. A small number of key individuals living in countries remote from Antarctica mobilized their personal networks and produced controversial and detailed reports of the illegal and unregulated fishery. Actions by these non-state actors included public and political awareness campaigns, voluntary monitoring schemes and informal pressure directed toward states and industries implicated in this fishery. Through such mechanisms, loosely connected non-state actors operating in different countries and in different fora were able to complement the roles of states and stimulated a growing political will and ability to effectively address the illegal fishery. The combined result is a multilevel global adaptive governance system for cooperation aimed at dealing with regional illegal and unregulated fishing. Although illegal and unregulated fishing has not completely disappeared, such fishing is currently substantially reduced through the complementary roles filled by state and non-state actors (Österblom and Sumaila 2011).

Dealing with Tipping Points and Thresholds, Across Levels and Scales

The fact that social–ecological change unfolds at multiple levels and across sectors poses serious problems related to institutional fragmentation and segmentation, crippling societies' ability to integrate information and coordinate effective responses (Galaz et al. 2010). Addressing climate change through forest plantations, for example, may replace ecosystems targeted by the U.N. Biodiversity Convention (Lambin and Meyfroidt 2011). Similarly, promotion of biofuels can accelerate deforestation and erode the food security of impoverished nations (Grau and Aide 2008). There is lack of effective institutions at the appropriate levels and of synthetic institutions that address interactions between biogeophysical and socio-economic systems (Walker et al. 2009b). Hence, current institutions run the risk of ignoring critical feedbacks, fail to address vulnerabilities that connect regions (Adger et al. 2009; Renaud et al. 2010) or are unable to respond to feedbacks to maintain or transform the social–ecological system into desirable and sustainable regimes (Chapin et al. 2010) (Fig. 7).

Such fragmentation poses severe global governance challenges, especially if planetary boundary (Rockström et al. 2009) or similar Earth System interactions result in rapid and unexpected change. Previous analyses show that institutional capacities tend to be severely outstripped when amplifying feedbacks either: (i) do not match previous experiences; (ii) embed scientifically and socially contested cause and effect relations; (iii) lead to secondary

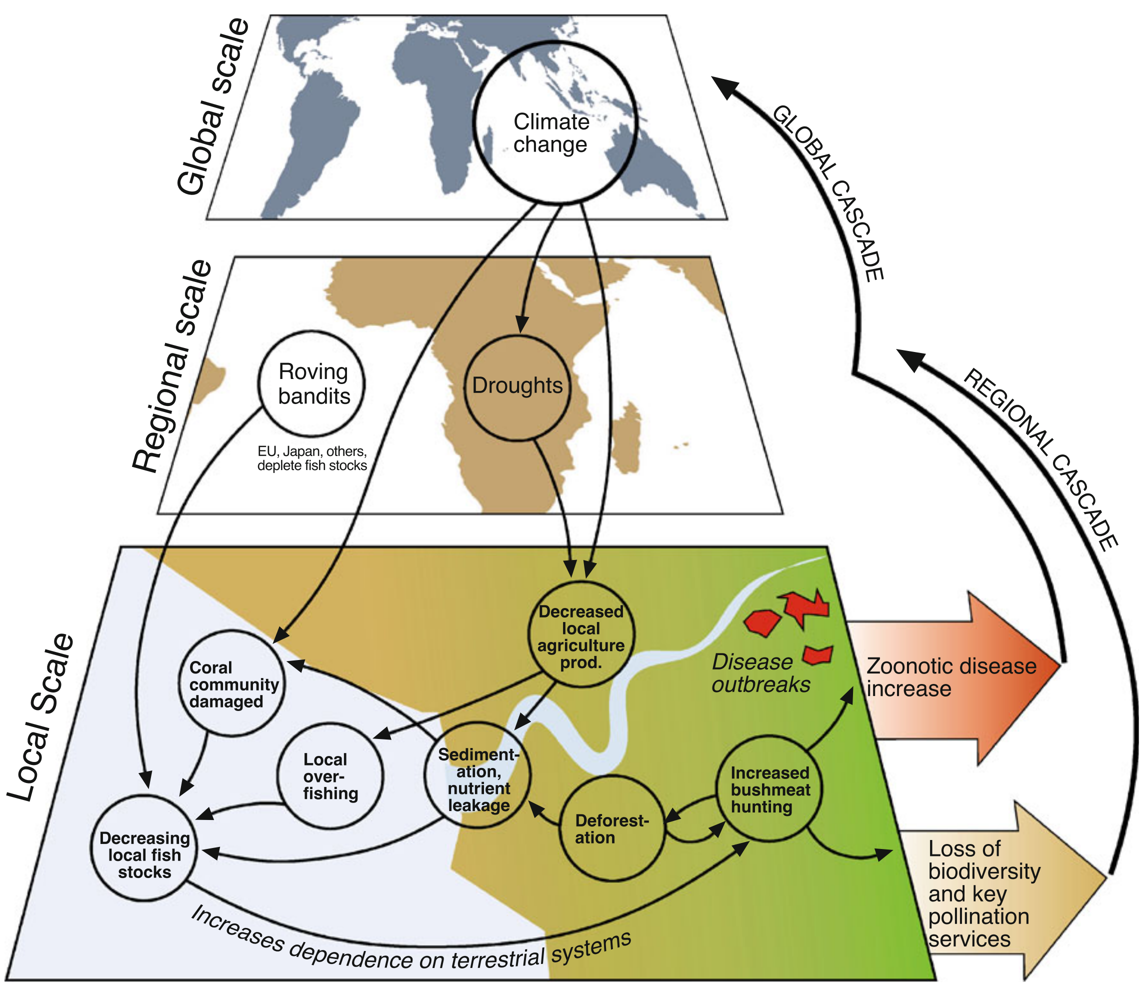

Fig. 7 Example of a multiple cascading social-ecological crises: fish and zoonotic disease (modified from Galaz et al. 2010)

effects that cascade rapidly in time and space; or (iv) when information integration and analysis are challenged by organizational silos and geographical and temporal gaps in ecological monitoring (Galaz et al. 2010).

There are no simple institutional panaceas for reversing current trends that challenge critical thresholds and tipping points in the Earth System, especially since these dynamics unfold from local to global level. The institutional solution or structures in themselves are not as important here as their capacity to allow for self-organization, coordinated action at multiple levels and learning from changing circumstances.

Some suggested strategies include the endorsement of inter-institutional learning through joint management among organizations (Oberthür 2009); science-based assessments aiming to promote inter-institutional learning and diffusion (Nilsson 2005); and giving environmental objectives ‘principled priority’ in cases where environmental and non-environmental institutions are in conflict (Lafferty and Hovden 2003). Another approach suggested is to more tightly coordinate and integrate existing institutions and international legal frameworks (such as the UNFCCC and the WTO) under the common notion of sustainable development (Voigt 2008).

Furthermore, if organized appropriately international knowledge institutions can play a fundamental role in facilitating a transparent, participatory and legitimate global dialogue on the need for reconnecting global policies with the biosphere. Both the IPCC and the Millennium Ecosystem Assessment are examples of global environmental assessment processes where not only outcome, but also the process of bringing together societal interests and scientific competence from different geographic regions of the world (Miller 2006; Mitchell et al. 2006) has been fundamental for legitimacy. There is an important opportunity now, with the launch of International Platform on Biodiversity and Ecosystem Services (IPBES) to integrate knowledge systems, learning and policy support, on social–ecological interactions in relation to climate change and ecosystem dynamics.

If we expand the analysis of options to multi-level governance, it is clear that a much greater range of responses with effects on global dynamics and Earth System interactions are available (Young et al. 2008). For example, food security as well as biodiversity and water impacts of the EU’s biofuel strategy, has recently come to the fore, through broadening the stakeholder discussions. Wider system boundaries when considering and assessing regional or national policies can thus be an important lever. Legal conceptions in environmental laws, but also on issues such as private property, corporate responsibility, and human rights—should better address insights on social–ecological resilience (Ebbesson 2010).

Planetary Stewardship and Global Sustainability

Planetary resilience is paramount to the world’s ability to cope with the multiple changes that are taking place and interact from local to global scales and Planetary Stewardship and Global Sustainability of human interactions with Earth System processes are emerging concepts in this context (e.g. Reid et al. 2010; Chapin et al. 2011). Planetary Stewardship provides a new and more compelling context for social–ecological scholarship and for developing strategies that link sustainability science to action (Fig. 8). Stewardship also opens doors for new collaborations, such as between ecologists and religious groups that share common goals of environmental stewardship and social justice, or between scientists and social psychologists for more effective communication of science with the public (Chapin et al. 2011).

A new research arena called Earth System Governance is developing focusing on the formal and informal rule systems, institutional architectures, agency beyond the state, and actor-networks at all levels of human society that are set up to steer societies toward preventing, mitigating and adapting to global environmental change (http://www.earthsystemgovernance.org) (Biermann et al. 2010). There are calls for renewed focus on what functions governance must fulfill in order to steer the Earth System and its interactions, simultaneously accounting for questions of accountability, transparency, winners and losers, and stakeholder engagement (Nilsson and Persson 2011). A key challenge yet to be realized in relation to Planetary Stewardship and Earth System Governance is to combine emergence of multi-lateral institutions and regime formation with mechanisms for incorporating biosphere understanding and capacity of responding to ecosystem dynamics into such efforts. This combination is particularly challenging as it includes elements of equity, legitimacy and self-determination of peoples.

As part of Earth System Governance, we suggest that the Millennium Development Goals should be reframed in a planetary stewardship context combined with calls for a new social contract for global sustainability. Social contracts play an important role in defining the reciprocal rights, obligations, and responsibilities between states and citizens. Global social–ecological change is creating new challenges and opportunities for both states and citizens, inevitably forcing a rethinking of existing and evolving social contracts in the light of ecosystem changes, more extreme weather events, and the consequences of social–ecological changes in distant locations (O’Brien et al. 2009; Walker et al. 2009b). Such a contract must transcend state borders and thus go beyond traditional notions of social contract. Also, a new social compound between science and society is needed to raise the effort, capability

Fig. 8 Shifting mind sets, a challenge for an urbanizing planet, Tokyo, Japan (photo Carl Folke)

and intensity of integrated science as a vehicle to explore planetary opportunities for transformations. The need for this social contract is urgent and must be addressed now.

CONCLUSION—KEY MESSAGES

Humanity has emerged as a major force in the operation of the biosphere, with a significant imprint on the Earth System. This new situation calls for a fundamental shift in perspectives and world views, reconnecting human development and progress to the biosphere and becoming active stewards of our role in the Earth System. The current mental disconnect of human progress and economic growth from the fundamental interactions with the biosphere has altered the long-term capacity of 'natural capital' to sustain societal developments. People and societies are integral components of the biosphere, depending on its functioning and life-support. It is urgent to start accounting for and governing natural capital and ecosystem services, not just for saving the environment but for the sake of our own development.

Resilience thinking is about thresholds and shifts among different pathways of development and provides a lens for capturing the interplay between gradual and abrupt, often surprising changes that now increasingly play out in cascading fashions in a world where everyone is in everyone-else's backyard. Drivers of change like rising human numbers, urbanization, migration patterns, emerging markets, diffusion of new technologies or social innovations may combine with sudden events like natural disasters, rapid shifts in fuel prices and volatile financial markets and generate unexpected outcomes. A major governance challenge in this context is to strengthen social–ecological systems to deal with such global links and feedbacks and to use them as opportunities for reconnecting societal developments to the biosphere.

Strategies for development that ignore the dynamics of the broader social–ecological system may push people into vulnerable situations and persistent traps and undermine the capacity to sustain human wellbeing in the long term. Science has responsibility to provide a better understanding of the challenges facing humanity, and to explore pathways toward a sustainable world. Global and regional scale integrated assessments, inclusive, transparent, and founded on an understanding of social–ecological interactions play a central role in building momentum for Planetary Stewardship.

New flexible forms of multilevel governance to deal with global sustainability, with institutional and economic support for experimentation and learning as a strategy to deal with complex social–ecological interactions are emerging in many places. The challenge of reconnecting to the biosphere should be central in such efforts.

Global social–ecological change is creating unprecedented challenges for both states and citizens, inevitably forcing a rethinking of existing and evolving social contracts. The ongoing shift from people and nature as separated parts to interdependent social–ecological systems provides exciting opportunities for societal development in collaboration with the biosphere—a global sustainability agenda for humanity.

Acknowledgments The article is based on Folke et al. (2011). Reconnecting to the Biosphere, Working Paper No.1. 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. We acknowledge support from Stiftelsen Futura, Ebba och Sven Schwartz Stiftelse, 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.

REFERENCES

Adger, W.N., H. Eakin, and A. Winkels. 2009. Nested and teleconnected vulnerabilities to environmental change. *Frontiers in Ecology and the Environment* 7: 150–157.

Andonova, L.B., and R.B. Mitchell. 2010. The rescaling of global environmental politics. *Annual Review of Environment and Resources* 35: 255–282.

Armitage, D., F. Berkes, and N. Doubleday (eds.). 2007. *Adaptive co-management: Collaboration, learning and multilevel governance*. Vancouver: UBC Press.

Arrow, K.J., B. Bolin, R. Costanza, P. Dasgupta, C. Folke, C.S. Holling, B.-O. Jansson, S. Levin, K.-G. Mäler, C. Perrings, and D. Pimentel. 1995. Economic growth, carrying capacity, and the environment. *Science* 268: 520–521.

Bennett, M. 2009. Markets for ecosystem services in China: An exploration of China's "Eco-compensation" and other market-based environmental policies. *Forest Trends*. http://www.forest-trends.org.

Berkes, F. 2009. Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management* 90: 1692–1702.

Berkes, F., and C. Folke (eds.). 1998. *Linking social and ecological systems: Management practices and social mechanisms for building resilience*. Cambridge: Cambridge University Press.

Berkes, F., T.P. Hughes, R.S. Steneck, J.A. Wilson, D.R. Bellwood, B. Crona, C. Folke, L.H. Gunderson, et al. 2006. Globalization, roving bandits, and marine resources. *Science* 311: 1557–1558.

Biermann, F., M.M. Betsill, J. Gupta, N. Kanie, L. Lebel, D. Liverman, H. Schroeder, B. Siebenhüner, and R. Zondervan. 2010. Earth system governance: A research framework. *International Environmental Agreements: Politics, Law and Economics* 10: 277–298.

Biggs, R., S.R. Carpenter, and W.A. Brocks. 2009. Turning back from the brink: Detecting an impending regime shift in time to avert it. *Proceedings of the National Academy of Sciences, USA* 106: 826–831.

Bodin, Ö., and B. Crona. 2009. The role of social networks in natural resource governance: What relational patterns make a difference? *Global Environmental Change* 19: 366–374.

Bowles, S., S. Durlauf, and K. Hoff (eds.). 2006. *Poverty traps*. Princeton: Princeton University Press.

Boyd, E. 2008. Navigating Amazonia under uncertainty: Past, present and future environmental governance. *Philosophical Transactions of the Royal Society B* 363: 1911–1916.

Boyd, E., and C. Folke (eds.). 2011. *Adapting institutions: Governance, complexity and social-ecological resilience*. Cambridge, UK: Cambridge University Press.

Brock, W.A., G. Engström, and T. Xepapadeas. 2011. *Energy balance climate models and the economics of climate change*. Beijer discussion paper 226, The Beijer Institute of Ecological Economics, Royal Swedish Academy of Sciences http://www.beijer.kva.se.

Brondizio, E.S., E. Ostrom, and O.R. Young. 2009. Connectivity and the governance of multilevel social-ecological systems: The role of social capital. *Annual Review of Environment and Resources* 34: 253–278.

Canadell, J.G., C. Le Quéréc, M.R. Raupacha, C.B. Fielde, E.T. Buitenhuise, P. Ciaisf, T.J. Conway, N.P. Gillette, et al. 2007. Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. *Proceedings of the National Academy of Sciences, USA* 104: 18866–18870.

Cao, S., B. Zhong, H. Yue, H. Zeng, and J. Zeng. 2009. Development and testing of a sustainable environmental restoration policy on eradicating the poverty trap in China's Changting County. *Proceedings of the National Academy of Sciences, USA* 106: 10712–10716.

Chapin III, F.S., G.P. Kofinas, and C. Folke (eds.). 2009. *Principles of ecosystem stewardship: Resilience-based natural resource management in a changing world*. New York: Springer Verlag.

Chapin III, F.S., S.R. Carpenter, G.P. Kofinas, C. Folke, N. Abel, W.C. Clark, P. Olsson, D.M. Stafford Smith, et al. 2010. Ecosystem stewardship: Sustainability strategies for a rapidly changing planet. *Trends in Ecology & Evolution* 25: 241–249.

Chapin III, F. S., S.T.A. Pickett, M.E. Power, R.B. Jackson, D.M. Carter, and C. Duke. 2011. Earth stewardship: A strategy for social-ecological transformation to reverse planetary degradation. *Journal of Environmental Studies and Sciences* 1: 44–53.

Crépin, A.-S., B.H. Walker, S. Polasky, W. Steffen, V. Galáz, C. Folke, and J. Rockström. 2011a. *Global dynamics, multiple shocks and resilience—planetary stewardship and catastrophic shifts in the Earth system*. Beijer discussion paper series 228. The Beijer Institute of Ecological Economics, Royal Swedish Academy of Sciences.

Crépin, A-S., J. Norberg, and K-G. Mäler. 2011b. Coupled economic-ecological systems with slow and fast dynamics—modelling and analysis method. *Ecological Economics* 70: 1448–1458.

Crowder, L.B., G. Osherenko, O.R. Young, S. Airame, E.A. Norse, N. Baron, J.C. Day, F. Douvere, et al. 2006. Resolving mismatches in U.S. ocean governance. *Science* 313: 617–618.

Cundill, G., and C. Fabricius. 2010. Monitoring the governance dimension of natural resource comanagement. *Ecology and Society* 15: 15. http://www.ecologyandsociety.org/vol15/iss1/.

Curran, L.M., S.N. Trigg, A.K. McDonald, D. Astiani, Y.M. Hardionon, P. Siregar, I. Caniago, and E. Kasischke. 2004. Lowland forest loss in protected areas of Indonesian Borneo. *Science* 303: 1000–1003.

Daily, G., T. Söderqvist, S. Aniyar, K. Arrow, P. Dasgupta, P.R. Ehrlich, C. Folke, A.M. Jansson, et al. 2000. The value of nature and the nature of value? *Science* 289: 395–396.

Deutsch, L., S. Gräslund, C. Folke, M. Huitric, N. Kautsky, M. Troell, and L. Lebel. 2007. Feeding aquaculture growth through globalization: Exploitation of marine ecosystems for fishmeal. *Global Environmental Change* 17: 238–249.

Dietz, T., E. Ostrom, and P.C. Stern. 2003. The struggle to govern the commons. *Science* 302: 1902–1912.

Eakin, H.C., and M.B. Wehbe. 2009. Linking local vulnerability to system sustainability in a resilience framework: Two cases from Latin America. *Climatic Change* 93: 355–377.

Ebbesson, J. 2010. The rule of law in governance of complex socio-ecological changes. *Global Environmental Change* 20: 414–422.

Enfors, E.I., and L.J. Gordon. 2008. Dealing with drought: The challenge of using water system technologies to break dryland poverty traps. *Global Environmental Change* 18: 607–616.

Falkenmark, M., and C. Folke. 2003. Freshwater and welfare fragility: Syndromes, vulnerabilities and challenges. *Philosophical Transactions of the Royal Society London, Biological Sciences* 358: 1917–2062.

Fitzherbert, E.B., M.J. Struebig, A. Morel, F. Danielsen, C.A. Brühl, P.F. Donald, and B. Phalan. 2008. How will oil palm expansion affect biodiversity? *Trends in Ecology & Evolution* 23: 538–545.

Folke, C., S.R. Carpenter, B.H. Walker, M. Scheffer, F.S. Chapin III, and J. Rockström. 2010. Resilience thinking: integrating resilience, adaptability and transformability. *Ecology and Society* 15: 20. http://www.ecologyandsociety.org/vol15/iss4/art20/.

Folke, C., T. Hahn, P. Olsson, and J. Norberg. 2005. Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources* 30: 441–473.

Folke, C., Å. Jansson, J. Larsson, and R. Costanza. 1997. Ecosystem appropriation by cities. *Ambio* 26: 167–172.

Folke, C., Å. Jansson, J. Rockström, P. Olsson, S. Carpenter, A-S. Crepín, G. Daily, J. Ebbesson, T. Elmqvist, V. Galaz, F. Moberg, M. Nilsson, H. Österblom, E. Ostrom, Å. Persson, S. Polasky, W. Steffen, B. Walker and F. Westley. 2011. Reconnecting to the biosphere, Working Paper No.1. 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.

Fraser, E.D.G., and A. Rimas. 2011. The psychology of food riots. *Foreign Affairs*, January 30.

Galaz, V., F. Moberg, E.-K. Olsson, E. Paglia, and C. Parker. 2010. Institutional and political leadership dimensions of cascading ecological crises. *Public Administration*. doi: 10.1111/j.1467-9299.2010.01883.x.

Galaz, V., T. Hahn, P. Olsson, C. Folke, and U. Svedin. 2008. The problem of fit between ecosystems and governance systems: insights and emerging challenges. In *The institutional dimensions of global environmental change: Principal findings, future directions*, ed. O. Young, L.A. King, and H. Schroeder. Boston, MA: MIT Press.

Gordon, L.J., G.D. Peterson, and E. Bennett. 2008. Agricultural modifications of hydrological flows create ecological surprises. *Trends in Ecology & Evolution* 23: 211–219.

Grau, H. R., and M. Aide. 2008. Globalization and land-use transitions in Latin America. *Ecology and Society* 13: 16. http://www.ecologyandsociety.org/vol13/iss2/art16/.

Grimm, N.B., S.H. Faeth, N.E. Golubiewski, C.L. Redman, J. Wu, X. Bai, and J.M. Briggs. 2008. Global change and the ecology of cities. *Science* 319: 756–760.

Gunderson, L.H., C.S. Holling, and S.S. Light (eds.). 1995. *Barrier and bridges to the renewal of ecosystems and institutions*. New York: Columbia University Press.

Gunderson, L.H., and S.S. Light. 2006. Adaptive management and adaptive governance in the everglades ecosystem. *Policy Science* 39: 323–334.

Gunningham, N. 2009. The new collaborative environmental governance: The localization of regulation. *Journal of Law and Society* 36: 145–166.

Hanson, C., J. Ranganathan, C. Iceland, and J. Finisdore. 2008. *The corporate ecosystem services review (version 1.0)*. Washington, DC: World Resources Institute.

Hoff, H. 2009. Global water resources and their management. *Current Opinion in Environmental Management* 1: 141–147.

Holling, C.S. 2004. From complex regions to complex worlds. *Ecology and Society* 9: 11. http://www.ecologyandsociety.org/vol9/iss1/art11.

Holling, C.S., F. Berkes, and C. Folke. 1998. Science, sustainability, and resource management. In *Linking social and ecological systems: Management practices and social mechanisms for building resilience*, ed. F. Berkes, and C. Folke, 342–362. Cambridge, UK: Cambridge University Press.

Jansson, A.M., M. Hammer, C. Folke, and R. Costanza (eds.). 1994. *Investing in natural capital: The ecological economics approach to sustainability*. Washington, DC: Island Press.

Kareiva, P., H. Tallis, T. Ricketts, G.C. Daily, and S. Polasky (eds.). 2011. *Natural capital: Theory & practice of mapping ecosystem services*. Oxford: Oxford University Press.

Kay, J.J., H.A. Regier, M. Boyle, and G. Francis. 1999. An ecosystem approach for sustainability: Addressing the challenge of complexity. *Futures* 31: 721–742.

Lafferty, W., and E. Hovden. 2003. Environmental policy integration: Towards an analytical framework. *Environmental Politics* 12: 1–22.

Lambin, E.F., and P. Meyfroidt. 2011. Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academy of Sciences, USA* 108: 3465–3472.

Lambin, E.F., H.J. Geist, and E. Lepers. 2003. Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources* 28: 205–241.

Leach, M., I. Scoones, and A. Stirling. 2010. *Dynamic sustainabilities: Technology, environment, social justice*. London: Earthscan.

Liu, J., S. Li, Z. Ouyang, C. Tam, and X. Chen. 2008. Ecological and socioeconomic effects of China's policies for ecosystem services. *Proceedings of the National Academy of Sciences, USA* 105: 9489–9494.

Lugten, G. 2010. *The role of international fishery organizations and other bodies in the conservation and management of living aquatic resources. FAO Fisheries and Aquaculture Circular. No. 1054*. Rome: FAO.

MA. 2005. *Millennium ecosystem assessment. Ecosystems and human well-being: Synthesis*. Washington DC: Island Press.

Mahon, R., L. Fanning, and P. McConney. 2009. A governance perspective on the large marine ecosystem approach. *Marine Policy* 33: 317–321.

Mäler, K.-G., S. Aniyar, and Å. Jansson. 2008. Accounting for ecosystem services as a way to understand the requirements for sustainable development. *Proceedings of the National Academy of Sciences, USA* 105: 9501–9506.

Matysek, K.A. 2009. Resilience and social-ecological systems: The UNESCO biosphere reserve program in Australia and Canada. PhD-Thesis, School of Geography and Environmental Studies, University of Tasmania.

McSweeney, K., and O. Coomes. 2011. Climate-related disaster opens 'window of opportunity' for rural poor in northeastern Honduras. *Proceedings of the National Academy of Sciences, USA* 108: 5203–5208.

Miller, C. 2006. Democratization, international knowledge institutions, and global governance. *Governance* 20: 325–357.

Mitchell, R., W.C. Clark, D.W. Cash, and N.M. Dickson (eds.). 2006. *Global environmental assessments: Information and influence*. Cambridge, MA: The MIT Press.

Nilsson, M. 2005. The role of assessments and institutions for policy learning: A study on Swedish climate and nuclear policy formation. *Policy Sciences* 38: 225–249.

Nilsson, M., and Å. Persson. 2011. Governance and institutions within the planetary boundaries: A backcasting methodology and example. *Ecological Economics* (in press).

Nordhaus, W.D., and J. Boyer. 2000. *Warming the world: Economic models of global warming*. Boston: MIT Press.

Oberthür, S. 2009. Interplay management: Enhancing environmental policy integration among international institutions. *International Environmental Agreements: Politics, Law and Economics* 9: 371–391.

O'Brien, K. 2009. Do values subjectively define the limits to climate change adaptation? In *Adapting to climate change: Thresholds, values, governance*, ed. W.N. Adger, I. Lorenzoni, and K. O'Brien, 164–180. Cambridge, UK: Cambridge University Press.

O'Brien, K., B. Hayward, and F. Berkes. 2009. Rethinking social contracts: Building resilience in a changing climate. *Ecology and Society* 14: 12. http://www.ecologyandsociety.org/vol14/iss2/art12/.

Odum, E.P. 1989. *Ecology and our endangered life-support systems*. Sunderland: Sinauer Associates.

Olsson, P., C. Folke, and T.P. Hughes. 2008. Navigating the transition to ecosystem-based management of the Great Barrier Reef, Australia. *Proceedings National Academy of Sciences, USA* 105: 9489–9494.

Olsson, P., and V. Galaz. 2009. Transitions to adaptive approaches to water management and governance in Sweden. In *Understanding transitions in water management*, ed. D. Huitema, and S. Meijerink. Cheltenham: Edward Elgar Publishing.

Österblom, H., and U.R. Sumaila. 2011. Toothfish crises, actor diversity and the emergence of compliance mechanisms in the Southern Ocean. *Global Environmental Change* 21: 972–982.

Österblom, H., M. Sissenwine, D. Symes, M. Kadin, T. Daw, and C. Folke. 2011. Incentives, social-ecological feedbacks and European fisheries. *Marine Policy* 35: 568–574.

Österblom, H., U.R. Sumaila, Ö. Bodin, J. Hentati Sundberg, and A.J. Press. 2010. Adapting to regional enforcement: Fishing down the governance index. *PLoS ONE* 5: e12832.

Ostrom, E. 2007. A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences, USA* 104: 15181–15187.

Ostrom, E. 2009. A general framework for analyzing sustainability of social-ecological systems. *Science* 325: 419–422.

Ostrom, E. 2010. Polycentric systems for coping with collective action and global environmental change. *Global Environmental Change* 20: 550–557.

Page, S.E., F. Siegert, J.O. Rieley, H.-D.V. Boehm, A. Jayak, and S. Limink. 2002. The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature* 420: 61–65.

Pahl-Wostl, C., P. Jeffrey, N. Isendahl, and M. Brugnach. 2011. Maturing the new water management paradigm: Progressing from aspiration to practice. *Water Resources Management* 25: 837–856.

Polasky, S., S.R. Carpenter, C. Folke, and B. Keeler. 2011a. Decision-making under great uncertainty: Environmental management in an era of global change. *Trends in Ecology and Evolution* 26: 398–404.

Polasky, S., A. de Zeeuw, and F. Wagener. 2011b. Optimal management with potential regime shifts. *Journal of Environmental Economics and Management* 62: 229–240.

Raudsepp-Hearne, C., G.D. Peterson, and E.M. Bennett. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences, USA* 107: 5242–5247.

Reid, W., V.D. Chen, L. Goldfarb, H. Hackmann, Y.T. Lee, K. Mokhele, E. Ostrom, K. Raivio, et al. 2010. Earth system science for global sustainability: Grand challenges. *Science* 330: 916–917.

Renaud, F.G., J. Birkmann, M. Damm, and G.C. Gallopin. 2010. Understanding multiple thresholds of coupled social-ecological systems exposed to natural hazards as external shocks. *Natural Hazards* 55: 749–763.

Rockström, J., W. Steffen, K. Noone, Å. Persson, S.F. Chapin III, E.F. Lambin, T.M. Lenton, M. Scheffer, et al. 2009. A safe operating space for humanity. *Nature* 461: 472–475.

Rosling, H. 2010. *Gapminder, for a fact-based worldview*. http://www.gapminder.org/.

Ruckelhaus, M., T. Klinger, N. Knowlton, and D.P. DeMaster. 2008. Marine ecosystem-based management in practice: Scientific and governance challenges. *BioScience* 58: 53–63.

Scheffer, M. 2009. *Critical transitions in nature and society*. Princeton, NJ: Princeton University Press.

Scheffer, M., J. Bascompte, W.A. Brock, V. Brovkin, S.R. Carpenter, V. Dakos, H. Held, E.H. van Nes, et al. 2009. Early-warning signals for critical transitions. *Nature* 461: 53–59.

Schultz, L., A. Duit, and C. Folke. 2011. Participation, adaptive co-management and management performance in the world network of Biosphere Reserves. *World Development* 39: 662–671.

Steffen, W., Å. Persson, L. Deutsch, J. Zalasiewicz, M. Williams, K. Richardson, C. Crumley, P. Crutzen, et al. 2011. The Anthropocene: From global change to planetary stewardship. *Ambio*. doi:10.1007/s13280-011-0185-x.

Steffen, E., P.J. Crutzen, and J.R. McNeill. 2007. The Anthropocene: Are humans now overwhelming the great forces of nature? *Ambio* 36: 614–621.

Steneck, R.S., T.P. Hughes, J.E. Cinner, W.N. Adger, S.N. Arnold, S. Boudreau, K. Brown, F. Berkes, et al. 2011. The gilded trap of Maine's lobster fishery: A cautionary tale. *Conservation Biology*. doi:10.1111/j.1523-1739.2011.01717x.

Stern, N. 2006. *Review on the economics of climate change*. H.M. Treasury, UK, October. http://www.sternreview.org.uk.

TEEB. 2011. *The economics of ecosystems and biodiversity in national and international policy making*. London: Earthscan.

UNEP. 2011. *The green economy initiative*. http://www.unep.org/greeneconomy/.

Voigt, C. 2008. *Sustainable development as a principle of international law: resolving conflicts between climate measures and WTO law*. Leiden: Martinus Nijhoff Publishers.

Walker, B.H., and J.A. Meyers. 2004. Thresholds in ecological and social-ecological systems: a developing database. *Ecology and Society* 9: 3. http://www.ecologyandsociety.org/vol9/iss2/art3.

Walker, B.H., J.M. Anderies, A.P. Kinzig, and P. Ryan. 2006. Exploring resilience in social-ecological systems through comparative studies and theory development: introduction to the special issue. *Ecology and Society* 11: 12. http://www.ecologyandsociety.org/vol11/iss1/art12/.

Walker, B.H., N. Abel, J.M. Anderies, and P. Ryan. 2009a. Resilience, adaptability, and transformability in the Goulburn-Broken Catchment, Australia. *Ecology and Society* 14: 12. http://www.ecologyandsociety.org/vol14/iss1/art12/.

Walker, B.H., S. Barrett, S. Polasky, V. Galaz, C. Folke, G. Engström, F. Ackerman, K. Arrow, et al. 2009b. Looming global-scale failures and missing institutions. *Science* 325: 1345–1346.

Walker, B.H., L. Pearson, M. Harris, K.-G. Mäler, C.-Z. Li, R. Biggs, and T. Baynes. 2010. Incorporating resilience in the assessment of inclusive wealth: An example from South East Australia. *Environment and Resource Economics* 45: 183–202.

Waltner-Toews, D., J.J. Kay, C. Neudoerffer, and T. Gitau. 2003. Perspective changes everything: Managing ecosystems from the inside out. *Frontiers in Ecology and the Environment* 1: 23–30.

Wennberg DiGasper, S. 2006. Already adaptive? An investigation of the performance of Swedish moose management organizations. Licentiate thesis 2006:09, Luleå University of Technology, p. 133.

Westley, F., P. Olsson, C. Folke, T. Homer-Dixon, H. Vredenburg, D. Loorbach, J. Thompson, M. Nilsson, et al. 2011. Tipping toward sustainability: Emerging pathways of transformation. *Ambio*. doi:10.1007/s13280-011-0186-9.

Wilson, J., L. Yan, and C. Wilson. 2007. The precursors of governance in the Maine lobster fishery. *Proceedings of the National Academy of Sciences, USA* 104: 15212–15217.

World Resources Institute. 2008. *Roots of resilience: Growing the wealth of the poor?*. Washington, DC: World Resource Institute.

Wunder, S., S. Engel, and S. Pagiola. 2008. Taking stock: A comparative analysis of payments for environmental services programs in developed and developing countries. *Ecological Economics* 65: 834–852.

Young, O.R., F. Berkhout, G.C. Gallopin, M.A. Janssen, E. Ostrom, and S. van der Leeuw. 2006. The globalization of socio-ecological systems: An agenda for scientific research. *Global Environmental Change* 16: 304–316.

Young, O.R., L.A. King, and H. Schroeder (eds.). 2008. *The institutional dimensions of global environmental change: Principal findings and future directions*. Boston, MA: MIT Press.

Zhang, P., G. Shao, G. Zhao, et al. 2000. China's forest policy for the 21st century. *Science* 288: 2135–2136.

AUTHOR BIOGRAPHIES

Carl Folke (✉) is Professor in natural resource management, Science Director of the Stockholm Resilience Centre at Stockholm University and Director of the Beijer Institute of Ecological Economics of the Royal Swedish Academy of Sciences. His research is on the role that living systems at different scales play in social and economic development and how to govern and manage for resilience in integrated social-ecological systems.
Address: Stockholm Resilience Centre, Stockholm University, 10691 Stockholm, Sweden.
Address: The Beijer Institute, Royal Swedish Academy of Sciences, PO Box 50005, 10405 Stockholm, Sweden.
e-mail: carl.folke@beijer.kva.se; carl.folke@stockholmresilience.su.se

Åsa Jansson Ph.D., works as researcher at the Beijer Institute of Ecological Economics of the Royal Swedish Academy of Sciences. She is partly employed as team leader at the Stockholm Resilience Centre, Stockholm University. Her research is on the role of ecosystem services and biodiversity in a sustainable development and human wealth context. The main focus is on the operationalization of the ecosystem services concept, through quantifying and valuing ecosystem services over space and time.
Address: Stockholm Resilience Centre, Stockholm University, 10691 Stockholm, Sweden.
Address: The Beijer Institute, Royal Swedish Academy of Sciences, PO Box 50005, 10405 Stockholm, Sweden.

Johan Rockström is Professor in natural resource management and Executive Director of the Stockholm Resilience Centre at Stockholm University and of the Stockholm Environment Institute. He research is on agricultural water management, watershed hydrology, global water resources, eco-hydrology, resilience and global sustainability.
Address: Stockholm Resilience Centre, Stockholm University, 10691 Stockholm, Sweden.
Address: Stockholm Environment Institute, Stockholm, Sweden.

Per Olsson is theme leader for Adaptive Governance, Networks and Learning at Stockholm Resilience Centre. He received his Ph.D. in natural resource management from Stockholm University. His research interest is in linked social-ecological system dynamics and resilience, and adaptive governance of social-ecological systems.
Address: Stockholm Resilience Centre, Stockholm University, 10691 Stockholm, Sweden.

Stephen R. Carpenter Professor, is Director of the Center for Limnology and S.A. Forbes Chair in Zoology at the University of Wisconsin-Madison, USA. His research concerns ecology, economics, governance and management of ecosystem services, especially freshwater resources.
Address: Center for Limnology, University of Madison, Madison, WI, USA.

F. Stuart Chapin III is Professor Emeritus in ecology at the Institute of Arctic Biology, University of Alaska Fairbanks and director of the graduate program in Resilience and Adaptation. His research is on design principles for social-ecological transformations in a rapidly changing world, with an emphasis on climate-change impacts in the north.
Address: Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, AK, USA.

Anne-Sophie Crépin is the Deputy Director of the Beijer Institute of Ecological Economics of the Royal Swedish Academy of Sciences and team leader for the global change and cross scale dynamics theme of the Stockholm Resilience centre. She holds a Ph.D. in Economics from Stockholm University. Her research focuses on modeling and analyzing the linkages and feedbacks between economic systems and ecosystems.
Address: Stockholm Resilience Centre, Stockholm University, 10691 Stockholm, Sweden.
Address: The Beijer Institute, Royal Swedish Academy of Sciences, PO Box 50005, 10405 Stockholm, Sweden.

Gretchen Daily is Bing Professor of Environmental Science in the Department of Biology and the Woods Institute at Stanford University; Director of the Center for Conservation Biology; and co-founder and faculty director of the Natural Capital Project. Her work is on quantifying the dynamics of change in biodiversity and ecosystem services, and on integrating the values of natural capital into decisions.
Address: Department Biology and Woods Institute for the Environment, Stanford University, Stanford, CA, USA.

Kjell Danell is Professor in wildlife ecology, Swedish University of Agricultural Sciences, Umeå. His research is on population ecology, plant-animal interactions, management and conservation of wildlife. He has performed field studies in boreal forests, African savannas and the Arctic.
Address: Department of Wildlife, Fish, and Environmental Studies, Swedish University of Agricultural Sciences, Umeå, Sweden.

Jonas Ebbesson is Professor of environmental law, Director of Stockholm Environmental Law and Policy Centre, Stockholm University and affiliated with the Stockholm Resilience Centre. His work focuses on various aspects of environmental law in an international

context, including public participation in decision-making, environmental responsibility of transnational corporations, the impact of law on the resilience of social-ecological systems, and justice considerations in environmental law and policy.
Address: Stockholm Resilience Centre, Stockholm University, 10691 Stockholm, Sweden.
Address: Environmental Law, Stockholm Environmental Law and Policy Centre, Stockholm University, Stockholm, Sweden.

Thomas Elmqvist is a professor in natural resource management at Stockholm University and affiliated with the Stockholm Resilience Centre. His research focuses on governance and management of ecosystem services in urban landscapes, ecosystem services and values, biodiversity in ecosystem dynamics, land use change, natural disturbances and components of resilience including the role of social institutions.
Address: Stockholm Resilience Centre, Stockholm University, 10691 Stockholm, Sweden.
Address: Natural Resource Management, Department of Systems Ecology, Stockholm University, Stockholm, Sweden.

Victor Galaz Ph.D., is researcher at the Stockholm Resilience Centre, Stockholm University. His current research and teaching focuses on adaptive governance and global governance of complex environmental risks such as pandemics and planetary boundaries. He has published extensively on institutional dimensions of resilience.
Address: Stockholm Resilience Centre, Stockholm University, 10691 Stockholm, Sweden.

Fredrik Moberg holds a Ph.D. in natural resources management from Department of Systems Ecology at Stockholm University. His research has mainly dealt with biodiversity, ecosystem services and resilience of the tropical coastal zone. Today he works as a communications advisor for Stockholm Resilience Centre and as the Director of Albaeco, an independent organisation communicating the latest in sustainability science.
Address: Stockholm Resilience Centre, Stockholm University, 10691 Stockholm, Sweden.
Address: Albaeco, Stockholm, Sweden.

Måns Nilsson is Deputy Director and Research Director at SEI and Visiting Professor in Environmental Strategies Research at the Royal Institute of Technology (KTH) in Stockholm. He received his Ph.D. degree in Policy Analysis from Delft University of Technology, Netherlands. He is interested in energy and climate policy, strategic assessment, innovation, European policy, and global governance.
Address: Stockholm Environment Institute, Stockholm, Sweden.

Henrik Österblom Ph.D., is a researcher at Baltic Nest Institute, Stockholm Resilience Centre, where he is theme leader for the research theme on Marine Governance. His research focuses on marine food-webs and governance, with a particular emphasis on the Baltic Sea, European and Antarctic fisheries and social-ecological feedback.
Address: Stockholm Resilience Centre and Baltic Nest Institute, Stockholm University, Stockholm, Sweden.

Elinor Ostrom is Arthur F. Bentley Professor of Political Science and Senior Research Director of the Workshop in Political Theory and Policy Analysis, Indiana University, Bloomington; and Founding Director, Center for the Study of Institutional Diversity, Arizona State University. Her research focuses on the impact of diverse institutional arrangement on effort to overcome social dilemmas related to public goods and common-pool resources. She is a recipient of the 2009 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 2009.
Address: Workshop in Political Theory and Policy Analysis, Indiana University, Bloomington, IN, USA.
Address: Center for the Study of Institutional Diversity, Arizona State University, Tempe, AZ, USA.

Åsa Persson is Researcher at the Stockholm Resilience Centre and Research Fellow at the Stockholm Environment Institute, Sweden. She received her Ph.D. in human geography from the London School of Economics and Political Science, UK. Her research now focuses on global environmental governance, in particular governance of and financial mechanisms for climate adaptation.
Address: Stockholm Resilience Centre, Stockholm University, 10691 Stockholm, Sweden.
Address: Stockholm Environment Institute, Stockholm, Sweden.

Garry Peterson is Professor in environmental sciences in the Stockholm Resilience Centre at Stockholm University. His research focuses on modelling and managing social-ecological systems for sustainable development.
Address: Stockholm Resilience Centre, Stockholm University, 10691 Stockholm, Sweden.

Stephen Polasky holds the Fesler-Lampert Chair in Ecological/Environmental Economics at the University of Minnesota, with appointments in the Department of Applied Economics, and the Department of Ecology, Evolution and Behavior. His research focuses on ecosystem services, biodiversity conservation, sustainability, and integrated ecological and economic analysis.
Address: The Beijer Institute, Royal Swedish Academy of Sciences, PO Box 50005, 10405 Stockholm, Sweden.
Address: Departments of Applied Economics and Ecology, Evolution, and Behavior, University of Minnesota, Minneapolis, MN, USA.

Will Steffen Professor, is Executive Director of the ANU Climate Change Institute at the Australian National University (ANU), Canberra, and serves on the Multi-Party Climate Change Committee (MPCCC) and as a Climate Commissioner. He is also Co-Director of the Canberra Urban and Regional Futures (CURF) initiative, a joint venture of ANU and the University of Canberra. From 1998 to mid-2004, Steffen served as Executive Director of the International Geosphere-Biosphere Programme, based in Stockholm, Sweden. His research interests span a broad range within the fields of climate change and Earth System science, with an emphasis on incorporation of human processes in Earth System modelling and analysis; and on sustainability and climate change, with a focus on urban systems.
Address: Stockholm Resilience Centre, Stockholm University, 10691 Stockholm, Sweden.
Address: The ANU Climate Change Institute, Australian National University, Canberra, ACT, Australia.

Brian Walker is a Research Fellow in Australia's CSIRO Division of Ecosystem Science and a visiting Fellow in the Stockholm Resilience Centre and Beijer Institute. Born in Zimbabwe he received his Ph.D. from the University of Saskatchewan. His research is on the dynamics and resilience of ecosystems and linked social-ecological systems.
Address: Stockholm Resilience Centre, Stockholm University, 10691 Stockholm, Sweden.
Address: The Beijer Institute, Royal Swedish Academy of Sciences, PO Box 50005, 10405 Stockholm, Sweden.
Address: CSIRO Sustainable Ecosystems, Canberra, ACT, Australia.

Frances Westley holds the J.W. McConnell Chair of Social Innovation, is Director of the Waterloo Institute for Social Innovation and Resilience (WISIR), and is a professor in the School for

Entrepreneurship, Environment and Development (SEED) at the University of Waterloo, Canada. She received her Ph.D. in Sociology from McGill University, Canada. Her research is in social innovation for resilience, transformation of linked social-ecological systems, inter-organizational and interdisciplinary collaboration and social/institutional entrepreneurship.
Address: Waterloo Institute for Social Innovation and Resilience, University of Waterloo, Waterloo, ON, Canada.