1 An introduction to the resilience approach and principles to sustain ecosystem services in social–ecological systems

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SUMMARY

A major challenge of the twenty-first century is ensuring an adequate and reliable flow of essential ecosystem services to meet the needs of the world's burgeoning and increasingly wealthy population. This challenge needs to be addressed in the face of rapidly changing social, technological and environmental conditions that characterize the world today. Social–ecological resilience is one fast-growing approach that attempts to inform this challenge and provide practical guidance to decision-makers and practitioners. The resilience approach views humans as part of the biosphere, and assumes that the resulting intertwined social–ecological systems behave as complex adaptive systems – i.e. they have the capacity to self-organize and adapt based on past experience, and are characterized by emergent and non-linear behaviour and inherent uncertainty. A rapidly growing body of research on resilience in social–ecological systems has proposed a variety of attributes that are important for enhancing resilience. This book aims to critically assess and synthesize this literature. In this chapter we introduce the resilience approach and the process by which we identified seven

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generic principles for enhancing the capacity of social–ecological systems to produce desired sets of ecosystem services in the face of disturbance and change.

1.1 CHALLENGES OF A RAPIDLY CHANGING WORLD

We live in an era of rapid and unprecedented change. The past century has seen the mass production and adoption of motor cars and telephones, a 15-fold increase in the global economy, large-scale conversion of land to agriculture and an increase in the global population from 1.6 billion people in 1900 to over 7 billion in 2011 (MA 2005a; Steffen *et al.* 2007) (Fig. 1.1). Despite ongoing challenges with addressing poverty, these rapid changes have brought huge benefits and dramatic improvements to many people's lives, particularly since the end of the Second World War in 1945 (MA 2005a; Steffen *et al.* 2007). Tellingly, for most of human history the average life expectancy was 20–30 years, reflecting the combined effects of poor nutrition, disease and warfare, especially on infant survival (Lancaster 1990). In 1900, the average global life expectancy still stood at 31 years, but by 2010 it had reached 67 years (CIA 2013), and is predicted to continue increasing and level off somewhere below 100 years (UN 2004). Millions of people today have access to a huge variety of goods, health, mobility and comforts that even kings and queens could not have dreamed of just a century ago.

However, there are growing concerns about whether these massive strides in human well-being can be sustained, and particularly whether substantially improving the lives of the 2.4 billion people who still live in poverty (World Bank 2014), as well as meeting the needs of the additional 1.5–2.5 billion people that are expected to join us on the planet by 2050 (UN 2013), is possible given the current trends of environmental degradation and change (MA 2005a; Intergovernmental Panel on Climate Change (IPCC) 2014). Despite huge technological advances, people still ultimately depend largely on nature for a variety of essential needs, including fresh air, clean water and food, protection from hazards such as droughts and storms, and a wide variety of cultural, spiritual and recreational needs that play a

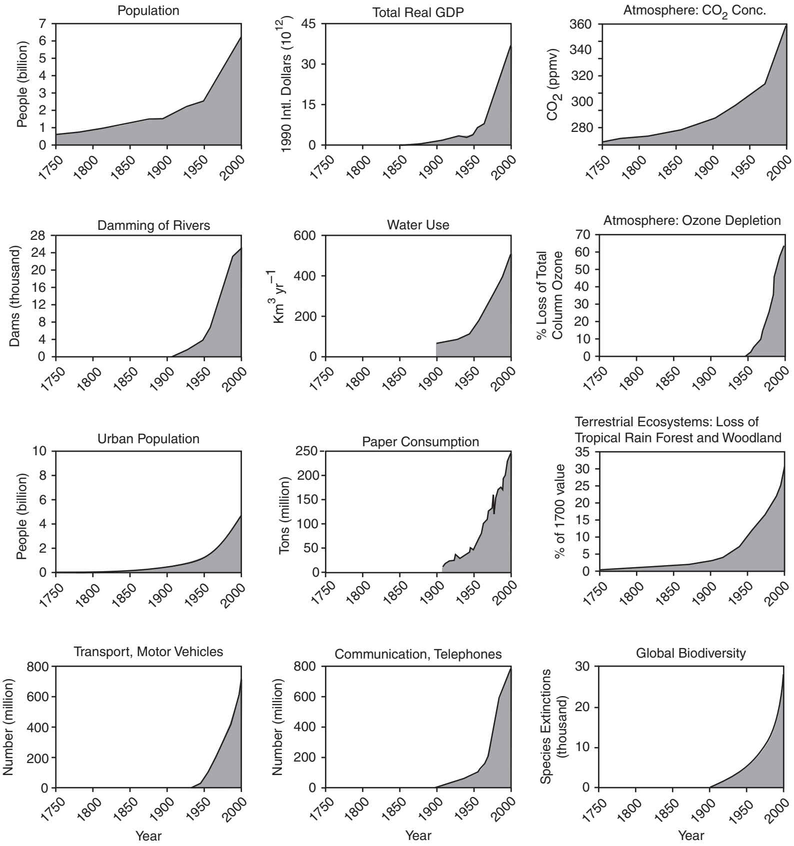

FIG. 1.1 Substantial increases in human activity have occurred over the past century, particularly since the end of the Second World War in 1945, with substantial impacts on the Earth's environment and functioning. These changes and impacts have often been even more pronounced in particular places and regions. From Steffen *et al.* (2011).

key role in human well-being (MA 2005a). Such benefits derived from the interaction of people with nature are known as ecosystem services (Ernstson 2013; Reyers *et al.* 2013; Huntsinger and Oviedo 2014).

There is growing evidence that the massive scale and extent of human activities such as agriculture, transport and release of novel chemicals are undermining the capacity of nature to generate key ecosystem services on which we depend (MA 2005a; IPCC 2014). For

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example, more than 50% of inland waters (excluding lakes and rivers) have been lost in parts of North America, Europe and Australia due to changes in land cover, drainage, infilling, invasive species and the effects of pollution, salinization and eutrophication (Finlayson *et al*. 2005). The cumulative impact of such activities on the biosphere – the thin layer of the Earth's surface and atmosphere that supports all life on Earth – is affecting the functioning of the planet, not just at local and regional scales, but at global scales (Steffen *et al*. 2004). Climate change provides a premier example. It is now well established scientifically that rising atmospheric carbon dioxide levels resulting from anthropogenic fossil-fuel combustion and land clearing are changing rainfall and temperature patterns around the world and leading to an increased incidence of extreme events such as droughts and storms (IPCC 2014). These changes are impacting food security, disease prevalence and infrastructure, as well as impacting traditional lifestyles and cultural practices that shape people's identity. They therefore pose direct threats to human security and well-being (IPCC 2014).

The profound shift to today's situation where human activities fundamentally shape the functioning of the planet, not just at local and regional scales but globally, has been suggested to mark a new geological era in the history of the Earth: the Anthropocene (Crutzen and Stoermer 2000). For most of human history, people had limited and localized impacts on the Earth's environment. If the environment became too degraded to support a community, people could usually move elsewhere (Diamond 2004). This started to change, however, with the onset of the industrial era in the 1800s. Particularly since the 1950s, human activities have been substantially impacting not just local and regional environments, but planetary functioning at a global scale (Steffen *et al*. 2007). This scaling up of the impact of human activities and the consequent changes to the functioning of the Earth system potentially have far-reaching and substantial consequences for the provision of key ecosystem services on which humanity depends.

A variety of novel and unpredictable effects that are difficult for society to cope with are of particular concern. Effects such as climate change, biodiversity loss, and changes in nutrient cycles are increasing the incidence of highly disruptive and unpredictable shocks such as large storms and disease outbreaks (MA 2005a; IPCC 2014). Human-induced changes to the environment are also increasing the potential for crossing critical thresholds or tipping points that could lead to large, non-linear and potentially irreversible changes at local through global scales, such as the death of coral reefs, shifts in regional monsoon rainfall patterns or collapse of the Greenland ice sheet (MA 2005a; Rockström *et al.* 2009; Barnosky *et al.* 2012). Beyond these somewhat known effects, our impacts on the environment are leading to completely novel changes that are very difficult to anticipate, and could have dramatic impacts on a variety of ecosystem services. The use of chlorofluorocarbons (CFCs) in refrigerators that led to the creation of the ozone hole is one example (Farman *et al.* 1985). Other examples include the potential emergence and spread of new diseases such as severe acute respiratory syndrome (SARS), or the potential consequences of nuclear proliferation and massively increased global connectivity and trade on the environment (Martin 2007).

The challenge of ensuring human well-being in the face of these rapid, ongoing changes to the environment and human society, and the substantial uncertainties they are generating, has given rise to a variety of new approaches and types of science (Gibbons *et al.* 1994; Funtowicz *et al.* 1999). One of these is the resilience approach (Walker and Salt 2006; Folke *et al.* 2010), which falls within the broad emerging field of sustainability science, a new research area that seeks to understand the interactions between nature and society in order to inform pressing sustainability challenges (Kates *et al.* 2001; Clark and Dickson 2003). Fundamental to the resilience approach is the assumption that people are embedded in the biosphere at local to global scales, where they interact with and help shape their environment, and are intricately dependent on it for a variety of ecosystem services that underpin human well-being (Berkes and Folke 1998; Berkes *et al.* 2003; Walker and Salt 2006). Resilience studies therefore focus largely on the study of intertwined social–ecological systems

(SES). These SES are assumed to behave as complex adaptive systems (CAS), i.e. they have the capacity to self-organize and adapt based on past experience, and they are characterized by emergent and non-linear behaviour, and generate substantial and sometimes irreducible uncertainties (Norberg and Cumming 2008). The resilience approach focuses specifically on the capacity of SES to deal with change in these kinds of systems. This includes not only recovery from unexpected shocks and avoiding undesirable tipping points, but also the capacity to adapt to ongoing change and fundamentally transform SES if needed (Walker *et al*. 2004; Folke *et al*. 2010).

Over the past two decades the resilience approach has attracted increasing attention, and there has been an explosion of research into system attributes that may promote or undermine the resilience of ecological systems, social systems and SES, and the ecosystem services upon which society depends (Gunderson and Holling 2002; Berkes *et al*. 2003; Walker and Salt 2006; Chapin *et al*. 2009; Boyd and Folke 2011). Given the diversity of potential attributes that affect resilience in SES, this research has drawn on a wide range of disciplines, including the social, economic, political and ecological sciences. A variety of potential factors have been proposed as key to building resilience based on theoretical and empirical research across a range of systems and case studies (Anderies *et al*. 2006; Walker and Salt 2006; Walker *et al*. 2006; Ostrom 2009). The diversity of disciplines and strands of resilience work involved has, however, led to a somewhat dispersed and fragmented understanding of the importance of different factors in different contexts. This fragmentation is limiting a coherent understanding of what factors are likely to be important for building resilience in a particular social–ecological setting, and how these factors can be practically operationalized to better manage SES in support of human well-being and long-term social and environmental sustainability.

This book aims to address this gap and help make sense of the large and growing body of work on resilience to identify key underlying principles for building resilience, and how these may be practically applied in real-world settings to advance sustainability. The book builds directly on an earlier review paper (Biggs *et al.* 2012b) that critically evaluated empirical evidence in support of various propositions and claims of factors that promote resilience of ecosystem services. We define resilience of ecosystem services as the capacity of SES to continue providing desired sets of ecosystem services in the face of unexpected shocks as well as ongoing change and development. Based on the paper and the work in this book we identify seven general principles for enhancing resilience of ecosystem services produced by SES: (P1) maintain diversity and redundancy, (P2) manage connectivity, (P3) manage slow variables and feedbacks, (P4) foster CAS thinking, (P5) encourage learning and experimentation, (P6) broaden participation and (P7) promote polycentric governance systems. These principles form the seven core chapters of the book, and throughout we cross-reference these chapters by their principle number and name (e.g. P1 – Diversity).

The first two chapters set the stage for the book. In this chapter we introduce the resilience approach, including its underlying rationale and assumptions. We introduce the concept of ecosystem services as a critical integrator between people and nature, and a potential focus for resilience-building initiatives and SES stewardship. Finally, we describe the process by which we identified the seven principles that form the core of this book. Before discussing the individual principles, Chapter 2 considers the social and political dimensions of ecosystem services, emphasizing that before applying any of the principles it is critical to reflect on which ecosystem services are the focus for resilience-building initiatives and who benefits and loses from these choices.

1.2 THE RESILIENCE APPROACH

Resilience is a perspective for the analysis of SES that emphasizes the need to understand and manage change, particularly unexpected change. Like other approaches within the sustainability science field, resilience studies are fundamentally problem-driven and integrate a variety of disciplinary approaches and perspectives to help address the considerable sustainability challenges facing society. The human–environment interactions at the core of sustainability science studies are, however, being conceptualized in a variety of ways, ranging from relatively loose links to strong interactive feedbacks between social and ecological system components. The resilience approach falls at the latter end of this spectrum.

Fundamental to the resilience approach is the notion that human society is embedded in and part of the Earth's biosphere. In this view, humans and nature are truly intertwined and interdependent: human action shapes ecosystem dynamics from local to global scales, while human societies rely on a wide variety of ecosystem services generated by SES for their well-being, including spiritual and psychological well-being (Folke 2006; Folke *et al*. 2011). In the resilience perspective, the SES resulting from these interactions are not seen as social plus ecological systems. Instead, they are seen as cohesive systems in themselves that occur at the interface between social and ecological systems, characterized by strong interactions and feedbacks between social and ecological system components that determine the overall dynamics of the SES (Fig. 1.2) (Folke *et al*.

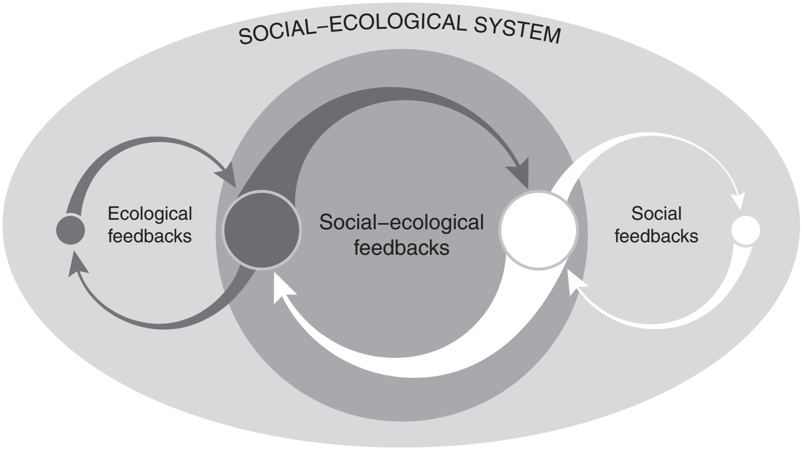

FIG. 1.2 In the resilience approach, SES are not simply seen as social plus ecological systems. Rather they are viewed as systems centred on the feedbacks between ecological (grey) and social (white) system components, which lie at the interface of social and ecological systems.

2010). A resilience approach thus moves beyond viewing humans as external drivers of ecosystem dynamics, as common in ecology or natural resource management, or natural resources as rather simple and constant inputs to production processes, as in economics. Instead it adopts an integrative analysis of complex interdependencies of actors, institutions and ecosystems across multiple scales (Gunderson and Holling 2002; Ostrom 2009; Boyd and Folke 2011).

Perhaps further setting it apart from several other approaches, the resilience perspective fundamentally assumes that SES behave as CAS (Folke 2006; Levin *et al*. 2013). In other words, SES have the capacity to self-organize and adapt or learn in response to internal or external disturbances and changing conditions, and are characterized by non-linear dynamics (Gros 2008). SES are seen as continuously evolving entities, with ongoing change arising from social–ecological interactions in the system, constrained and shaped by a given social–ecological setting (Gunderson and Holling 2002; Folke 2006). The diversity of SES components is seen as essential for this self-organizing ability as heterogeneity provides a source of variation for adaptation (P1 – Diversity) (Levin 1999). However, given the nature of SES as CAS, change is not uniform and continuous. Rather, periods of gradual change can be interrupted by rapid and sudden, often unexpected change (P3 – Slow variables and feedbacks) (Holling 2001).

From a resilience perspective, change is therefore an inherent characteristic of SES. The resilience approach views disturbance and change not necessarily as something negative that should be avoided, but as an inherent feature of SES that presents ongoing opportunities for renewal and improvement (Gunderson *et al*. 1995; Holling 2001; Gunderson and Holling 2002). Shocks, disturbance and crises are seen as particularly important in opening up opportunities for reorganization. These opportunities are shaped by the conditions and dynamics of systems at both smaller and larger scales (Gunderson *et al*. 1995; Gunderson and Holling 2002). A resilient SES is seen as a system that persists and maintains its capacity to sustain ecosystem services and human well-being in the face of disturbance, both by buffering shocks but also through adapting and reorganizing in response to change (Walker *et al*. 2004; Folke *et al*. 2010). Resilience thus deals with the tension between persistence and change, i.e. on the one hand understanding and managing the capacity to absorb shocks and maintain function, but on the other hand also to maintain the capacity for renewal, reorganization and development at a variety of scales (Folke 2006).

Changes in SES are understood to take place at a variety of interlinked organizational, spatial and temporal scales, with some changes occurring slowly and others faster. Interactions between individual SES components at lower scales or levels give rise to the macro-scale properties of the system, which are often emergent features that are not predictable from the lower-level components or interactions. For example, mechanization encouraged the cultivation of marginal land by individual farmers on the US Great Plains in the 1920s. When a severe drought struck in the 1930s, the amount of bare land was so extensive that it gave rise to massive dust storms never previously seen in the region (Peters *et al*. 2008). Such macro-scale conditions in turn affect local-level processes and actions (Gunderson and Holling 2002; Norberg and Cumming 2008). In the case of the US Dust Bowl, this led to severe soil erosion, human health impacts and the abandonment of farms by tens of thousands of families (Worster 2004). This example illustrates how processes at different scales in an SES can interact and lead to unexpected outcomes. Policies based only on local-scale dynamics can lead to wrong judgements about the macro-scale state of an SES, and inappropriate actions, and vice versa. The emergence of such macro-scale behaviour, interacting timescales and complex interactions and feedbacks across scales make the behaviour of SES inherently difficult to predict. Analysing and modelling SES with simple linear and reductionist dynamics, as has been common for example in mainstream economics, often gives a misleading representation of how SES work, with substantial implications for ecosystem management policy and practice (Levin *et al*. 2013).