Chapter 17
What Can We Do Better for Sustainability in an Uncertain Future?

Li Xu and Talia Raphaely

Abstract Sustainability is a significant challenge confronting a changing world. With an increasingly uncertain future ahead for human wellbeing, achieving, social–ecological sustainability is more than just a simple goal. The new imperative for natural resources management sheds is how to avoid the collapse of social–ecological systems as a result of external shocks triggered by climate change and anthropogenic perturbations. Building up resilient social–ecological systems is therefore an urgent issue for sustainability science. Using water resources management as an example, this paper discusses the need to introduce resilience thinking into sustainability science, how such a thinking should be incorporated into sustainability management for adapting to the growing uncertainties, and how social–ecological resilience can be enhanced.

Keywords Sustainability · Social–ecological systems · Resilience thinking · Perturbations, water, management, uncertainty, climate change

Introduction

Sustainability (or sustainable development) was introduced as a concept in the 1980s and directed people's consideration towards environmental health and human development. Although definitions abound, one of the most enduring is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). However, global environmental issues—such as water scarcity, food security, peak oil, climate change and natural catastrophes including increasing instances of unexpected external and internal shocks such as earthquakes, extreme climate events

L. Xu · T. Raphaely (✉)
Curtin University, GPO Box U1987, Perth, WA 6845, Australia
e-mail: T.Raphaely@curtin.edu.au

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and tsunamis—have become an inevitable truth and a barrier to achieving the goal of sustainability (Barnosky et al. 2012; UNEP 2012). The realisation of social–ecological sustainability is not a simple aspiration but a huge challenge, the achievement of which is necessary for human well-being in the face of the changing world.

Since sustainability is not a "steady state" or "fixed target", achieving the goal of sustainable development requires continuous adjustments that respond to changing conditions, knowledge and priorities (Dale et al. 2013). Integrated natural resources management needs to find optimal ways for effective actions in order to avoid social–ecological systems collapse directly resulting from external shocks triggered by nature and human-induced perturbations. Building social–ecological resilience, by improving the ability of the system to withstand such shocks without changing its original state or domain of attraction, could enhance the likelihood of successful sustainability in an uncertain future (Walker et al. 2004; Adger et al. 2005; Folke 2006; Xu et al. 2015). This chapter discusses why resilience thinking is needed to address sustainable development and how we should use this thinking to build social–ecological resilience for water resource management in an uncertain future.

Sustainability and Uncertainty in Water Resource Management

Water resource sustainability is "the ability to use water in sufficient quantities and quality from the local to the global scale to meet the needs of humans and ecosystems for the present and the future to sustain life, and to protect humans from the damages brought about by natural and human-caused disasters that affect sustaining life" (Mays 2007, p. 4). Freshwater is essential for survival of the living world (Wetzel 2000; Long et al. 2003) and is a prerequisite for the continuity and advancement of human societies (Postel and Carpenter 1997). However, the growing severity of freshwater scarcity has become an increasing threat with freshwater systems directly impacted, damaged and depleted by human activities and anthropogenic climate change. For example, at the turn of this century, about 80 % (at the time almost 5 billion people) of the world's population lived in areas where either incidental human water security or biodiversity threats exceeded the 75th percentile (Vörösmarty et al. 2010). This situation has worsened although no specific figures are available. In China, two-thirds of this country's 669 cities are facing water shortages and 80 % of lakes are affected by eutrophication (Chinese Academy Science 2007; Liu and Yang 2012). Due to increasing demand, high pollution levels and the resulting decline in freshwater ecosystems (Johnson et al. 2001), limits of water availability and related considerations of water security have become major threats in the 21st century (Bismas 1991; Vörösmarty et al. 2010).

The highly uncertain future of water is caused mainly by human and climate-related impacts and changes. The complexity of social–ecological systems gives rise to a variety of projection variables on climate change. These in turn increase uncertainties regarding impacts and consequences of the interaction between the internal mechanisms of social–ecological processes and the impact of external influences (changes) on these systems. The changing impacts of climate extremes on water systems—including floods, droughts and storms—depend not only on changes in the characteristics of climate-related variables but also on water-relevant non-climatic stressors, management characteristics and adaptive capacity (IPCC 2012). For example, climate change has the potential to impact on river flood characteristics by changing the volume and timing of precipitation or by changing evaporation and hence accumulated soil moisture deficits. However, there is considerable uncertainty in the magnitude, frequency and direction of these changes. For freshwater adaptive management, Folke (2003) advocates a shift in thinking arguing that resilience needs to be strengthened to secure and provide the possibilities for prosperous societal development. Folke reasons that active management should be undertaken to help maintain the essential role of freshwater in dynamic landscapes faced with uncertainty and shock (moving from command-and-control to complex systems thinking).

Resilience Thinking for Sustainability

The concept of resilience for ecosystems and social–ecological systems is one of the declared focussed research areas within the sustainability discourse (Levin et al. 1998). A bibliometric analysis on resilience thinking shows it is a dominant approach within the sustainability paradigm, especially when it comes to climate change adaptation and dealing with human impacts and disturbance issues (Xu and Marinova 2013), and its value has been proven in the past decade. To better integrate the concept of resilience into sustainable management of resources facing an uncertain future, the rest of this chapter seeks to provide a definition of resilience processes, the ways in which resilience can be incorporated into the sustainability discourse using water resource management as an example, and, finally, to outline some of the possible future directions such an approach might take.

Defining Resilience for Water Resource Sustainability

Resilience was introduced by Holling into ecological systems theory in 1973 and is generally defined by the Resilience Alliance as “the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes” (Resilience Alliance 2012).

Social–ecological resilience is the capacity of the system to absorb regular perturbations or uncertain disturbances from natural hazards—such as floods, typhoons or hurricanes—by retaining their essential functions, structures, processes and feedbacks (Walker and Salt 2006; Adger et al. 2005). Applying resilience thinking to sustainability requires a definition of resilience tailored for the specific system being studied. The first question to answer is "resilience *of what* and *to what*" namely *what* system state is being considered and to *what* disturbances does resilience apply. Also important is defining resilience over *what time period*, *to whom* and *at what scale* (Carpenter et al. 2001). As sustainability encompasses three main pillars (environment, economy and society), there is a need to consider the concept of resilience in these three contexts before defining *of what* and *to what* for water resource sustainability. Ecological (or environmental) resilience describes the ability of an ecosystem to absorb environmental disturbances as well as its capacity for renewal, reorganisation, learning, adaptation and development. It includes the degree to which the system is capable of self-organisation and the degree to which the system can build the ability for learning and adaptation to the external perturbations (Carpenter et al. 2001; Folke et al. 2002). Economic resilience refers to "the ability of the system to withstand either market or environmental shocks without losing the capacity to allocate resources efficiently (the functionality of the market and supporting institutions), or to deliver essential services (the functionality of the production system)" (Perrings 2006, p. 418). Social resilience emphasises the time it takes to recover from stress and, more importantly, the access of a community to critical resources such as water (Langridge et al. 2006), land, finances and human skills.

Three key words can be captured from the definition of resilience above. These are *capacity, disturbance* and *state*. *Capacity* is the ability of a system to absorb external shocks and mainly encompasses renewal, reorganisation, learning and adaptation when coping with disturbance. *Disturbance* is the different sorts of undesirable or unpredictable changes or perturbations to a system caused by nature and human activities and includes natural shocks such as floods, storms, earthquakes and hurricanes and human-induced perturbations such as engineering constructions, timbering, land reclamation and rangeland. *State* is the responses of a system to the disturbance. Resilience requires the system to be able to maintain a desirable state and not change to a qualitatively different state when facing with the disturbances.

Accordingly, resilience of sustainable water resource management can be defined as

> The ability of water resources systems to withstand uncertainty and disturbance without shifting into an undesirable state by maintaining abilities of renewal, reorganization, learning and adaptation, to provide sufficient quantities of good quality water to meet the needs of humans and ecosystems for both current and future generations.

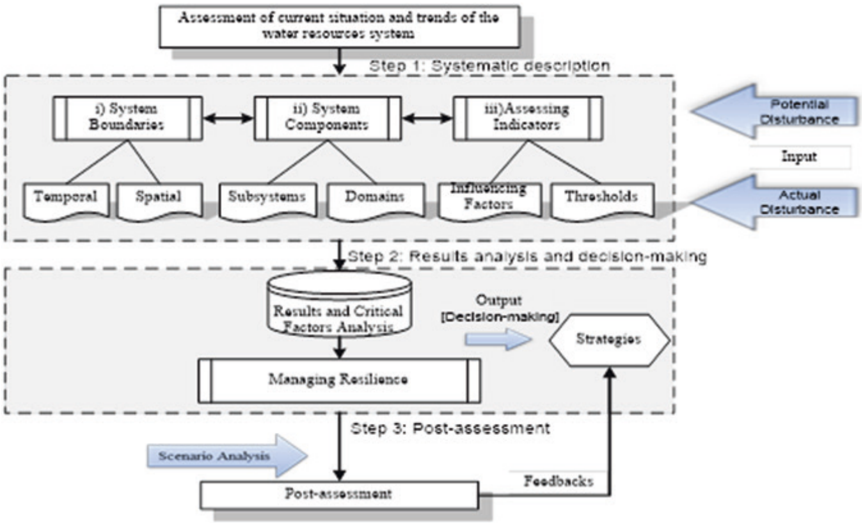

Fig. 17.1 Procedure of incorporating resilience thinking into the sustainable management of water resource systems. *Source*: Own Graphic

Incorporating Resilience into Sustainable Water Management

The most important step for incorporating resilience thinking into sustainable water management is to identify and understand the current circumstances and trends of social–ecological systems. This requires identification and assessment of potential and actual disturbance and external shocks based on their impacts on the sustainability of the specific system being investigated. Once this is accomplished, optimal management strategies can be explored and recommended.

The process of incorporating resilience thinking into the sustainable management of water resource systems is shown in Fig. 17.1.

As Fig. 17.1 shows, the procedure of incorporating resilience into the sustainable management of water resource systems consists of three main steps:

Step 1: *Systematic description*; in this step, three significant interacting characteristics of water resources systems are described from a systematic perspective. One of the primary tasks for resilience analysis is to define resilience over a specific time period, a specific scale and resilience for whom. The critical questions which need to be answered before achieving sustainability are *over what space and time* is sustainability to be achieved? (Bell and Moore 2008, p. 14).

1. The description starts with defining the boundaries of the studied water resource system on a spatial and temporal scale. For example, when assessing the social–ecological sustainability of a lake, the spatial scale can be defined as

the scale of the area which should be assessed in conjunction with the lake, or the areas in which users of the lakes resources live. In addition, the time scale over which the assessment is to be carried out should also be clarified during this step. The definition must be made on the basis of certain specified criteria including a definition of the concept of resilience and sustainability or the average service life of infrastructures in the studied water system.

2. The second part of step 1 is to identify the various components of the system in question. This can be done through defining what subsystems are involved in the specified system and what domains are included in the assessment. In general, ecological, economic and social systems are the key domains used in terms of sustainability. Ecological systems include components relating to environmental quality and ecological health. Economic systems relate to those sectors which have a relationship with production and consumption of the specified resource. Social systems are usually communities and people that have direct interaction with the specified resource.
3. The third and final part of the description is to develop a set of indicators for sustainability within resilience thinking. Two sorts of disturbances need to be considered in this step: actual disturbances (disturbances that have already occurred) such as engineering constructions, and potential disturbances (that may or are likely to occur) such as extreme floods. To do this, the factors influencing sustainability within the system should be identified. That is, what kinds of factors could affect the state of the system and what are the main forces that control these factors? In addition, there is also a need to identify whether there are any tipping points (thresholds), especially critical ones, which determine or could create shifts in the state of system. It is known that ecological systems have tipping points within their components. Whilst the socioeconomic system tipping points, components and causes are more difficult to determine and sometimes less recognised, they are also critically important considerations to consider and include. The likelihood of system transition may gradually increase as the system approaches a tipping point whereupon a minor trigger can invoke "a self-propagating shift to a contrasting state" (Scheffer et al. 2012). Unpredictable external shocks and disturbances increase the possibility of these changes. Certain generic indicators may be useful for identifying the tipping points of a system and detecting if the system is close to the critical tipping point (Scheffer et al. 2012).

Step 2: *Results analysis and decision-making*; this step focuses mainly on managing social–ecological resilience around water resources systems through strategy planning and policy design. Based on the *systematic description* comprising step 1, step 2 focuses on analysing key factors affecting the state of sustainability of the system and critical thresholds that should be considered when confronting external disturbances and strategies for enhancing systems' resilience. Certain planning approaches could be useful in achieving beneficial sustainability outcomes here. For instance, multi-objective planning (MOP) could be one of the options encouraging systematic consideration of multiple objectives including environmental, social, regional, and economic and others (Major 1977). Specific objectives must be defined prior to applying MOP in order to optimise strategies designed for enhancing social–ecological resilience. It is important to recognise any constraints that may create obstacles in achieving the defined objectives. The constraints are identified and determined by disturbance variables, critical influencing factors and tipping points of the system as well as by the conditions of the different components within the overall system.

Step 3: *Post-assessment*; this final step evaluates if the strategies are useful for the enhancement of social–ecological resilience and sustainability of the system. This can be done by observation or simulation. Whilst observation is an effective evaluation option, it is time-consuming and costly due to the lengthy timeframes typically needed in strategy implementation and outcomes. This is particularly true of restoration plans. Consequently a simulation approach, such as a scenarios analysis or computer-based method, is highly recommended as an alternative. This post-assessment is necessary because it can assess the anticipated performance of strategies. It is also a good way to provide feedback to decision-makers for proposed strategy adjustments.

Building Up Social–Ecological Resilience for Water Resources System

Structured scenarios and active adaptive management are two useful tools for building resilience in social–ecological systems. This includes stimulating building resilience in social–ecological systems, creating open institutions for learning and flexible collaboration and directing actions towards building adaptive capacity. Further, motivating the development of indicators and warning signals of gradual change and loss of resilience and thresholds, and encouraging learning and incorporation of ecological knowledge into institutional structures in multi-level governance (Folke et al. 2002; Adger et al. 2005) are important. Social–ecological resilience can also be built up by policy design that strengthens understanding of humanity and nature as interdependent.

Many studies have been conducted regarding building social–ecological resilience, mostly centred on initiatives enhancing collective actions through engaging stakeholders (Folke et al. 2002), co-management (Tompkins and Adger 2004) and legislation (Olsson et al. 2004). Additionally, building indigenous ecological knowledge-based systems, multi-level governance and polycentric institutions are proving to be a helpful means of facilitating institutional and social learning and multi-level governance through education and training (Adger et al. 2005; Silici et al. 2011). However, more research is required to better understand how to manage resilience for sustainability. This includes further exploration of multi-scale effects, further evaluation of environmental, social and economic trade-offs, enhanced monitoring and evaluation strategies and continuing engagement with stakeholders.

Building social–ecological resilience for water resource systems should follow seven general principles described by Folk et al. (2000):

1. Designing management strategies based on traditional local ecological knowledge. Local ecological knowledge may expand sources of information for ecosystem management (Becker and Ostrom 1995). Local water use knowledge, including biological knowledge and knowledge of ecological processes, may complement and enhance scientific knowledge;
2. Designing management systems that "flow with nature";
3. Developing local ecological knowledge for understanding cycles of natural and unpredictable events;
4. Enhancing social mechanisms;
5. Promoting conditions for self-organisation and institutional learning;
6. Rediscovering adaptive management; and
7. Developing values consistent with resilient and sustainable social–ecological systems. Moreover, attempts to build resilience for social–ecological systems should capture and address slow variables that affect resilience rather than trying to control disturbance. This is because change can be inevitable or unobservable but still potent as is the case with climate change, nutrient stocks and soil properties (Folke et al. 2002).

This requires improved understanding of social–ecological systems dynamics and the incorporation of knowledge obtained from and by local users to gain greater insight into how systems respond to potential tipping point shocks (Berkes and Folke 1998; Carpenter et al. 2001; Folke et al. 2002). It also requires efficient management interventions. It is, however, important to realise that management interventions can either build or destroy resilience depending on how the social–ecological system is able to organise itself and respond to management actions. Therefore, ongoing assessment is advised to establish if strategy or intervention adjustments are appropriate.

The Way Forward

Social–ecological sustainability is essential for human well-being in an increasingly uncertain future. The urgent issue for natural resources management is to prevent social–ecological systems from collapsing in the face of external shocks triggered by climate change and anthropogenic perturbations. Establishing and enhancing social–ecological resilience for the sustainable management of natural resources could address this urgent challenge. However, the research on resilience and sustainability is still in the exploratory stage with more attention needed on integrating the abundant ecological evidence with socio-economic aspects and the role of human activities in shaping ecosystems. Future research around resilience and sustainability could focus on questions such as how to identify and manage the key drivers and elements of resilience within social–ecological systems, how to monitor and evaluate whether adopted resilience building strategies are working and how to identify and engage with stakeholders when building social–ecological resilience.

More specifically, it is important to identify and quantify the tipping points (thresholds) for key elements of social–ecological systems and to find the drivers which affect these elements and thereby the state of the system. Appropriate indicators may be useful for achieving this, and they can detect if the system is close to the critical tipping point (Scheffer et al. 2012).

Another important issue for sustainability management into the future concerns how to build flexible institutions with the ability to adjust to changing environmental conditions. This is increasingly significant in a world of growing uncertainty and shock and requires consideration of the dynamics of affected social–ecological systems when considering the sustainable use of water and any other resource. Long-term observation of vulnerable systems needs to be established including frequent monitoring of environmental conditions. Information feedback to institutions should be monitored and assessed. Appropriate indicators (especially early warning indicators) should be developed to ensure the long-term resilience of systems under observation. Perhaps most critically for sustainability, local stakeholders need to be involved in any policy development and management programme to ensure the best result for both the people and the environment.

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