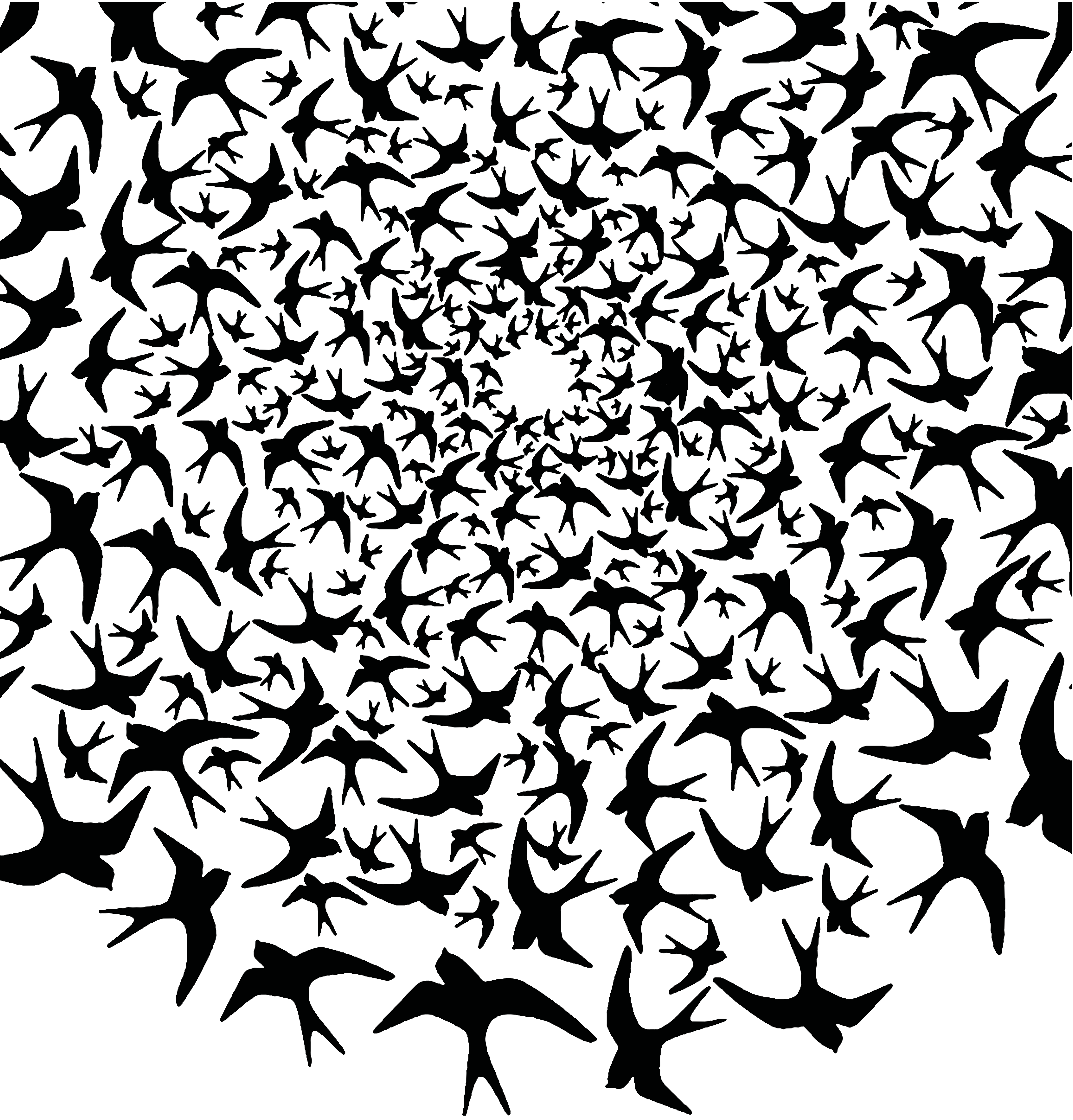

Operationalizing Resilience

Conceptual, Mathematical and Participatory Frameworks for Understanding, Measuring and Managing Resilience.

Ariella Helfgott | School Of Mathematical Sciences | The University Of Adelaide

Thesis Declaration

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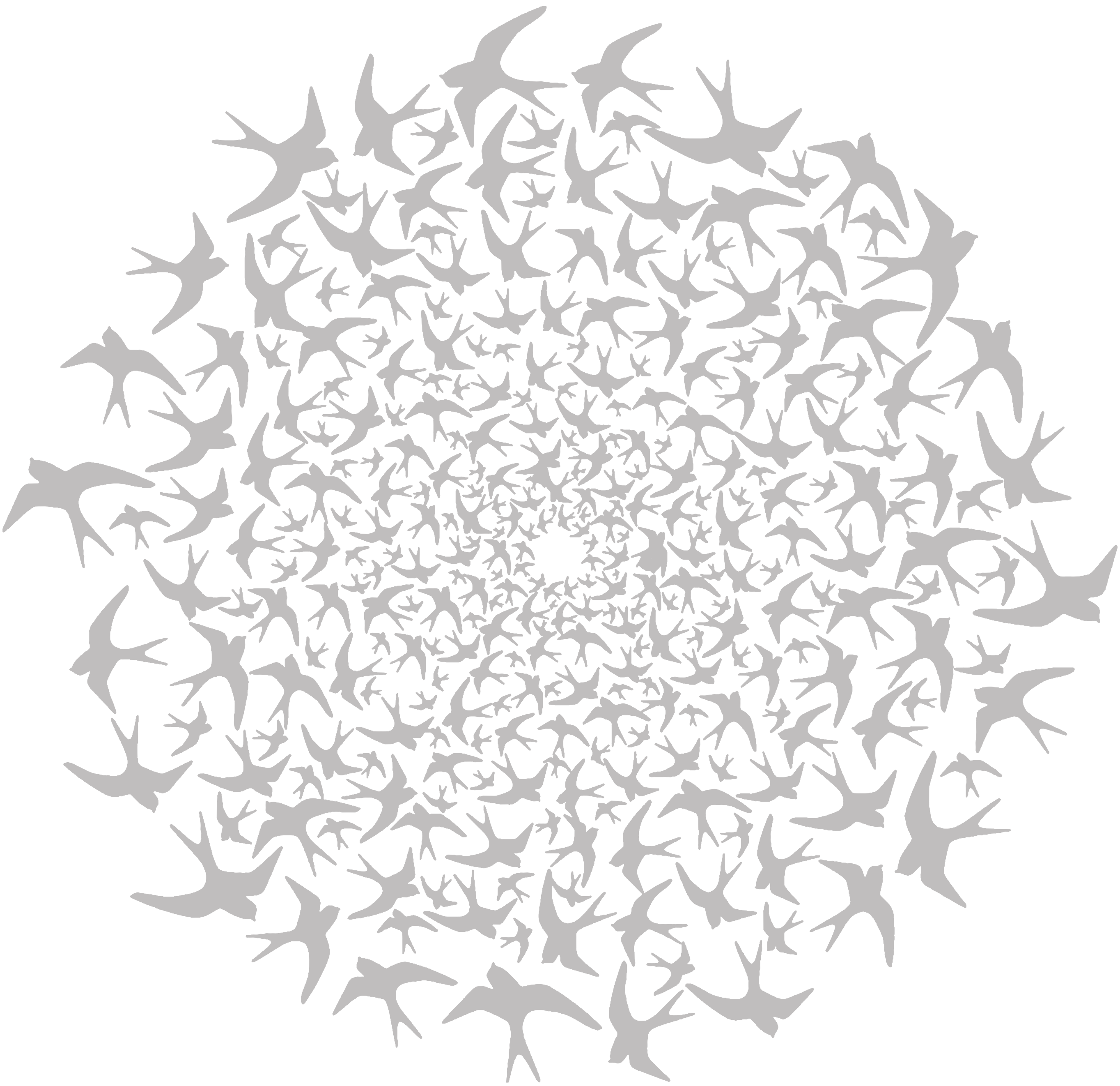

This thesis is dedicated to Arieh and Annita Helfgott,
to whom I owe my resilience.

Ariella Helfgott

School of Mathematical Sciences,
The University of Adelaide

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This thesis has been 10 years in the making and there are many people, who have shaped my thinking and my life during that time, that I cannot thank enough. My deepest thanks go to my primary supervisor, Professor Nigel Bean, without whom this work simply could not have happened. Nigel's willingness to support truly exploratory, interdisciplinary research enabled this thesis. He was constantly present, available, supportive, encouraging, and never once became impatient throughout a very exploratory, lengthy and risky journey that travelled well outside of his own disciplinary specialties and interests. Nigel has been with me every step of the way and has contributed to my thinking in each aspect of this thesis. My second supervisor, Dr. David Matthews, provided crucial insight and inspiration through his own work on systems thinking. I owe much of my own thinking on systems thinking to him. My third supervisor, Dr. Matthew Roughan, had a significant role in the early days of this thesis, supporting my exploration of complex systems science as it relates to resilience.

I am grateful to the School of Mathematical Sciences for providing me with a PhD scholarship. I am also grateful to the Defence Science Technology Organisation (DSTO) within the Australian Department of Defence and to the Environmental Change Institute (ECI) at the University of Oxford, which both provided me with stimulating work environments through which I further developed my thinking and practice. My employment at the ECI provided me with the opportunities to apply for large research program funding, which gave rise to the Systemic Integrated Resilience and Adaptation (SIRA) research program.

I am extremely grateful to CCAFS for their support of the SIRA research progam, particularly Dr. Andrew Jarvis, Dr. Osana Bonilla Findji and Dr. Sonja Vermeulen, who provided intellectual feedback and practical support as well as funding. At the same opportunity, I must thank the SIRA team: Chase Sova, Meghan Bailey, Jessica Thorn, Abrar Chaudhury and Adeyemi Ademiluyi, who worked together with me as an interdisciplinary team to apply the frameworks presented in this thesis in Nepal and Ghana. They took part in organizing and facilitating the participatory action research activities described in Chapters 5, 6 and 8.

I am indebted to Dr. Steven Lord for his contribution to the mathematical framework for resilience that corresponds to the conceptual and operational frameworks presented in this thesis. The process of developing the mathematical framework together greatly shaped my thinking on resilience. Steven has provided razor-sharp feedback and insight on many relevant topics, including scenario development and Fuzzy Cognitive Maps.

I have a profound sense of gratitude to my ECI and CCAFS colleague, Dr. Joost Vervoort, who is the Principal Investigator of CCAFS Regional Scenarios program. Joost and I have worked seamlessly together across 8 countries over the past 4 years to integrate the SIRA and regional scenarios programs. Joost and I have co-facilitated workshops for both programs. This collaboration has been highly stimulating and educational and I am grateful for the support and inspiration Joost has provided.

The mode of research undertaken in this thesis has been greatly influenced by the example my father set in his own work. He taught me to relentlessly pursue rigorous understanding of a topic, even if it meant I had to acquire new knowledge, skills, and engage with new disciplines and sectors and chart unknown territory. I am grateful to both of my parents for providing me with an excellent education, both formally and informally, and instilling in me the values and the habits which have allowed me to undertake my work and to write this thesis. This thesis is dedicated to them, since I owe them my personal resilience.

I thank Professor Terrance Hughes for introducing me to the concept of resilience and setting me on this path. Though the work we did together with Dr. Sean Connolly and Dr. Andrew Baird, mathematically modelling the resilience of the Great Barrier Reef, falls outside of the scope of this thesis, the process we went through together greatly informed my subsequent work, which is described here.

I thank Jennifer Russell for kindly proofreading and copyediting this thesis, and for providing a great deal of encouragement and support throughout this process. I thank Mavra Design for typesetting, cover and chapter divider design.

Abstract

We live in a turbulent world, in which there is growing awareness and concern about of unpredictable and interconnected change across scales. We cannot predict, still less control every source of change that affects systems on which we depend. However, we can aspire to be resilient in the face of change. We can seek to build resilience so that when disturbances happen, those systems have the capacity to absorb, adapt to, utilize and possibly even benefit from perceived disturbances. We can seek to manage systems such that, when they do fail, they fail gracefully; and such that we can effect desirable transitions and transformations. This thesis presents a practical theory of system resilience to facilitate improved management and governance of systems such that their capacity to sustain human and natural capital is enhanced. In order to do so, it addresses questions of what system resilience is, how it is measured, how it is created or destroyed and what we can do, as humans, in order to manage resilience. It provides direct methodological pathways from conceptual and mathematical models of resilience to approaches for characterizing and managing resilience on-the-ground.

Resilience has received an enormous amount of attention across an extensive range of disciplines and sectors. It has become a central theme of research, policy and practice from local to global scales. However, the global spread of resilience has not resulted in global definitions. The inherent conceptual and operational pluralism extant in the field is problematic for those involved in resilience management, planning and decision-making; particularly in the multi-actor and multi-scale processes that are called for by the very concept of resilience. Acknowledging interconnectedness of social, economic, political and environmental systems across scales and levels, taking into account cross-scale and cross-level interactions, and striving towards holism are fundamental aspects of the resilience approach. Thus, frameworks that can handle this diversity across disciplines, sectors and social worlds scales are needed. This thesis has presented systemic frameworks for understanding, measuring and managing resilience that are designed to work with and capitalize on this inherent pluralism and accordingly build capacity to cope with uncertainty and change.

The frameworks presented have been applied tested by the author through the Systemic Integrated Resilience and Adaptation program. Applications to understanding and managing the resilience of agricultural communities in Nepal, for integrated multi-level resilience and adaptation in Ghana and a global level food systems model.Relevant resilience planning frameworks and the approaches taken to cross-level, cross-scale and cross-research program integration have been described. Finally the frameworks are applied to the design and implementation of interdisciplinary resilience research programs. The lessons learned from these applications are discussed, guidelines for understanding, measuring, managing and researching resilience are provided and directions for further research and action are highlighted.

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1. Introduction

1.1. Motivation

We live in a turbulent world. The current state of global affairs conveys a widespread perception of unpredictable changes across scales (Sonnenfeld and Mol 2011). 'Structures that had provided for some predictability are breaking down and a trend towards uncertainty and unpredictability is likely to characterize the present and foreseeable future' (Arrighi and Silver 2001). We cannot predict, still less control, every source of change that affects the systems on which we depend. However, we can aspire to be resilient in the face of change. We can seek to build resilience so that, when disturbances happen, those systems have the capacity to absorb, adapt to, utilize and possibly even benefit from perceived disturbances (Holling 1973). We can seek to manage systems such that, when they do fail, they fail gracefully; and such that we can effect desirable transitions and transformations. Accordingly, the study of resilience has become increasingly important.

This thesis seeks to facilitate those goals through the development of frameworks for understanding, measuring and managing resilience. This work is motivated by the author's passion for the interdependent issues of sustainable development, poverty alleviation and environmental change and management. Accordingly, there is a focus on these themes in the applications of the resilience frameworks provided in this thesis.

1.2. Background

Resilience has received an enormous amount of attention across an extensive range of disciplines and sectors, from local to global scales, with escalating intensity over the past four decades (Folke 2006, Leach 2008, Young et al. 2006, Bhamra, Dani, and Burnard 2011, Martin-Breen and Anderies 2011, Walker et al. 2004, Walker et al. 2006). The concept has been subjected to protracted debates regarding its theoretical grounding, its practical applicability and its critical connotations (Brand and Jax 2007, Levine et al. 2012, Klein, Nicholls, and Thomalla 2003). Resilience has become a central theme in the strategies and policies of businesses, NGOs, governments and global institutions (Starr, Newfrock, and Delurey 2003, Birchall and Ketilson 2009, Council of Australian Governments 2009, Government of Nepal 2010, Thompson 2009, European Commission 2012, World Bank 2011, United Nations Office for Disaster Risk Reduction 2007).

However, the global spread of resilience has not resulted in global definitions, and may never do. There are as many different understandings of both the concept and application of resilience as there are practitioners, each with practical reasons for adopting a particular interpretation in their context relevant to the problems they address. Resilience has been described as a boundary object (Brand and Jax 2007). Boundary objects are concepts that are loosely structured in common use and only obtain strong structure and meaning in a particular context. They are flexible and interpreted differently in different disciplines, sectors and social worlds, but have enough common substance to be recognizable (Star and Griesemer 1989).

In the midst of different positions; organizations, researchers and practitioners are struggling with the tensions between different understandings and practices for management and governance of human and natural systems. Uncertainty and lack of clarity about what resilience means in practice permeates the entire field. The various different and often contradictory understandings of resilience and associated concepts cause considerable difficulty for those involved in research, decision-making and policy development. Therefore, resilience is sometimes rejected, its usefulness questioned, and there is confusion on how to operationalize and apply the concept.

This thesis reviews and synthesizes existing conceptual frameworks for resilience. Based on this, it develops a coherent and internally consistent interdisciplinary conceptual framework for resilience that any particular instantiation can be situated within. It is capable of including the sense of resilience across disciplines while being rigorous enough to permit mathematical formulation. A mathematical framework for resilience that corresponds to the conceptual framework presented has been developed. It is described and applied to an illustrative example of modelling the resilience of global food systems.

1.3. Objectives

The overarching objectives of the thesis are:

- Review and synthesize existing:
    - Conceptual frameworks for resilience;
    - Mathematical frameworks for resilience.
- Develop a coherent and internally consistent conceptual framework for system resilience and related ideas such as adaptability and transformability. The conceptual framework should be adequate to:
    - Capture the subtleties of meaning of the terms as they are used across and within disciplines;
    - Enable descriptive, explanatory and planning activities;
    - Provide a basis for mathematical reasoning and computer based simulations.
- Provide discussion of the broad implications of the conceptual framework.
- Initiate and promote wider discourse regarding its subject matter.
- Present through application a mathematical framework that corresponds to the conceptual framework. The intention is that the mathematical framework should be adequate to:
    - Uniquely quantify resilience;
    - Enable descriptive, explanatory, exploratory; and - within the world views being represented - predictive activities.
    - Enable quantitative comparison of different management and governance strategies for resilience;
    - Facilitate the proposal of new hypotheses.
- Provide methodological support in application of the conceptual and mathematical

frameworks to real-world problems.

- Provide case studies of application of the conceptual and mathematical frameworks to real-world problems.
- Provide methodological support for building resilience on-the-ground.
- Make proposals regarding how to make further progress.

1.4. Conclusions

This thesis seeks to provide a practical theory of system resilience to facilitate improved management and governance of systems such that their capacity to sustain human and natural capital is enhanced. In order to do so, it must address questions of what system resilience is, how it is measured, how it is created or destroyed and what we can do, as humans, in order to manage resilience. It then seeks to provide a direct methodological pathway from conceptual and mathematical models of resilience to approaches and techniques for characterizing and managing resilience on-the-ground.

Chapter 2 addresses questions of what resilience is. It reviews, synthesizes and critiques existing conceptual frameworks for resilience across disciplines and sectors, and provides the basis for the interdisciplinary conceptual framework provided in Chapter 4. The author contributed to a publication titled 'Adaptive Management of the Great Barrier Reef and the Grand Canyon World Heritage Areas' and this work contributed to the social-ecological resilience section of Chapter 2 (Hughes et al. 2007).

Chapter 3 addresses questions of how resilience can be measured. It reviews, synthesizes and critiques existing mathematical frameworks for resilience across disciplines and sectors. Chapter 3 also informs the conceptual framework presented in Chapter 4. It also provides the basis for a corresponding mathematical framework for measuring resilience. A paper based on this chapter is in preparation to be published in Global Environmental Change.

Chapter 4 presents an internally consistent and coherent conceptual framework for resilience, that captures the meaning of the term as it is used across disciplines, but is rigorous and consistent enough to allow mathematical formulation (Lord 2007a, b, c). The conceptual framework presented in this chapter improves upon the conceptual framework for resilience that the author developed earlier in her research and published as DSTO research reports under the research agreement with the University of Adelaide titled 'Resilience, Robustness and Adaptability: Implications for National Security, Safety and Stability' (Helfgott and Lord 2006, Helfgott and Burke 2006).

Chapter 5 presents an operational framework for applying the conceptual framework in practice. This chapter draws together systems thinking, strategic planning and international development theory and practice to provide a direct methodological pathway for practical application of the conceptual framework presented in Chapter 4 for understanding, managing and measuring resilience in real-world applications. The following chapters are all applications of the operational framework to social and environmental issues. Chapter

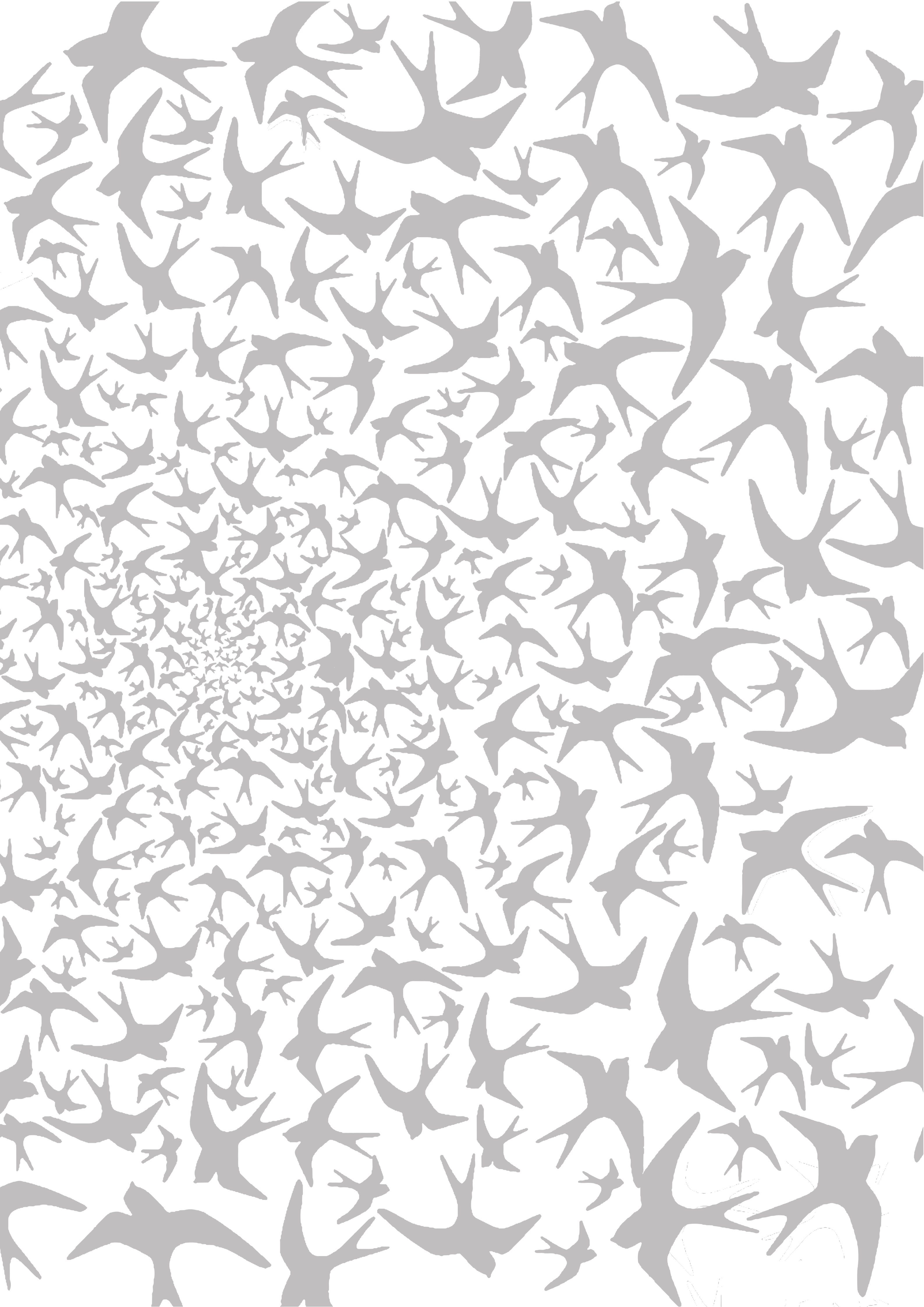
6 applies the operational framework to understanding and managing resilience, Chapter 7 applies it to modelling and measuring resilience, Chapter 8 applies it to researching resilience.

The participatory methodology presented in Chapter 5 has been published as a manual by the CGIAR Climate Change, Agriculture and Food Security Research Program (Helfgott, Vervoort, and Bailey 2014) and the United Nations Environment Program, with modifications for the context of protected areas (UNEP-WCMC 2014). A paper based on the material presented in Chapter 5 is in preparation to be submitted to Ecology and Society (Helfgott et al. In preparation).

Chapter 6 applies the operational framework to characterizing and building resilience of agricultural communities on the Terai plains of Nepal to climate change. Chapter 6 is based on a paper submitted to Technological Forecasting and Social Change (Helfgott, Bailey, et al. 2014).

Chapter 7 applies the operational framework to modelling and measuring the resilience of global food systems to a range of shocks including climate change, food price fluctuations and changes in agricultural practices and technologies. A paper, based on Chapter 7, clarifying the mathematics of Fuzzy Cognitive Maps (FCM) for participatory modelling has been submitted to Global Environmental Change (Helfgott, Bean, et al. 2014). Insights about the use of FCM for modeling resilience have been contributed to a paper submitted to Ecology and Society (Gray et al. 2014). A paper that more comprehensively covers the material of Chapter 7 is in preparation for submission to Global Environmental Change.

Chapter 8 describes the Systemic Integrated Resilience and Adaptation research program that was designed based on the operational framework presented in Chapter 5. It provides guidance for resilience research program design, and interdisciplinary research more generally. A paper based on this chapter is in preparation for submission to Research Evaluation.



2.

Conceptual Frameworks for Resilience

2. Review of Existing Conceptual Frameworks for Resilience

2.1. Introduction

Resilience has received an enormous amount of attention across an extensive range of disciplines and sectors, from local to global scales, over the past four decades (Folke, 2006, Leach, 2008, Young et al., 2006, Bhamra et al., 2011, Martin-Breen and Anderies, 2011, Walker et al., 2004, Walker et al., 2006). The concept has been subjected to protracted debates regarding its theoretical grounding, its practical applicability and its critical connotations (Brand and Jax, 2007, Levine et al., 2012, Klein et al., 2003). Resilience has become a central theme in the strategies and policies of businesses, NGOs, governments and global institutions (Starr et al., 2003, Birchall and Ketilson, 2009, Council of Australian Governments, 2009, Government of Nepal, 2010, Thompson, 2009, European Commission, 2012, World Bank, 2011, United Nations Office for Disaster Risk Reduction, 2007).

However, the global spread of resilience has not resulted in global definitions, and may never do. There are as many different understandings of both the concept and application of resilience as there are practitioners; each with practical reasons for adopting a particular interpretation in their context relevant to the problems they address. Resilience has been described as a boundary object (Brand and Jax, 2007). Boundary objects are concepts that are loosely structured in common use and only obtain strong structure and meaning in a particular context. They are flexible, interpreted differently in different disciplines, sectors and social worlds, but have enough common threads to be recognizable (Star and Griesemer, 1989). Sustainability is another example of a boundary object.

This chapter seeks to review and synthesize existing conceptual frameworks for resilience extant in literature and practice and to draw out these common threads. It does not cover every such conceptual framework, as that would take many volumes and years, if it is indeed even possible, given the proliferation of material in almost every sphere. What it does is provide a representative spectrum of the ways resilience can be conceived, and presents a coherent conceptual framework that any particular instantiation can be situated within.

The review focuses primarily on engineering, ecology, environmental management, sociology, development, disaster management, and psychology. The reason for this choice of scope is the focus of this thesis on the nexus between poverty alleviation, sustainable development, and environmental management; or the resilience of human and natural systems to environmental change. Reference is made to the evolution of these concepts and their usage.

2.2. Engineering resilience

The term, 'resilience', was first formally used in physics and engineering, where it was defined as the capacity of a material to absorb energy when it is deformed elastically, and, upon unloading, to have this energy recovered and to 'spring back' and regain its original shape. It is the maximum energy per unit volume that can be elastically stored. This is a physical property of a material that does not change. It is represented by the area under the curve in the elastic (linear) region of the materials stress-strain diagram.

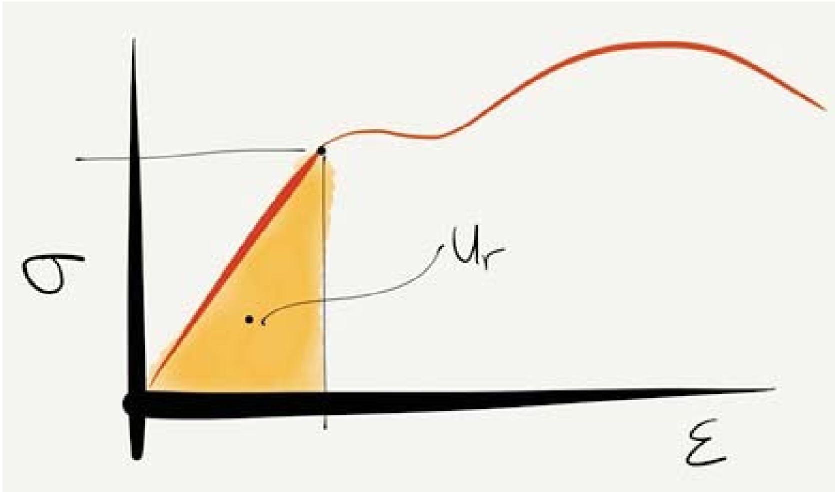


Figure 2.1. Stress (σ)-strain(ε) diagram of an elastic material showing the Modulus of Resilience Ur as the area under the elastic portion of the curve.

The 'modulus of Resilience', Ur, can be calculated using the following formula

$$Ur = \frac{\sigma^2}{2E} = 0.5 * \sigma * \varepsilon,$$

where σ is yield stress, E is Young's modulus, and ε is strain. This is a physical property of a material (Campbell, 2008). This information is important for engineers to choose materials and design dimensions for different purposes from bridges to cars or space shuttles.

The conceptualization of resilience is used in many fields of engineering apart from material science, including structural and water engineering to describe the capacity of an engineered system[1] to absorb, recover and spring back to a predefined state following some predefined disturbance. This understanding of resilience often fits well with the role of an engineer who is responsible for providing consistent, reliable and safe function of the engineered system, irrespective of changes in external circumstances, or internal changes due to maintenance of component failure. Consider, for example, the role of the water engineer, who is responsible for designing water storage and distribution systems capable of maintaining a continuous volumetric flow rate to people's houses in the face of varying inflows and outflows to the system, changes in pressure and temperature in the environment and within the pipe system and so forth. For the water engineer with this task, understanding resilience as the capacity of the water storage and distribution system to absorb such changes and maintain the required flow rate, or recover quickly if need be, makes sense.

[1] Examples include a bridge, building, water supply infrastructure, refrigerator, computer.

2.3. Ecological Resilience

Early work in ecology adopted the idea of resilience from physics and engineering in its entirety. The term, resilience, was used to define the capacity of an ecosystem to resist a perturbation or to return to equilibrium after having been subjected to shock (Holling, 1973). In this context, resilience was taken to express the notion of a system's stability around a point of equilibrium (Holling, 1996, Gunderson, 2000). It includes two components, resisting perturbation in the first place, that is, maintaining the original state and, secondly, returning to the same equilibrium if a shock causes a change from the original state. Some examples of this notion of ecological resilience include the following definitions:

- '[Resilience is a] measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables' (Holling, 1973).
- '[Ecological resilience is] a characteristic of ecosystems to maintain themselves in the face of disturbance' (Adger, 2000b).
- '…how fast a variable that has been displaced from equilibrium returns to it. Resilience could be estimated by a return time, the amount of time taken for the displacement to decay to some specified fraction of its initial value' (Pimm, 1991).
- 'The capacity of an ecosystem to resist a perturbation or to return to equilibrium after having been subjected to shock' (van der Leeuw and Aschan-Leygonie, 2005).

This conceptualization of resilience as stability around a particular equilibrium leads to consideration of return times and return paths to the original state, whether or not there is hysteresis (see 2.3.1 below), whether or not we stay in the neighbourhood of the original equilibrium – often visualized as staying within the same 'basin of attraction' or moving to an 'alternate stable state'. Key concepts associated with this understanding of resilience, namely, hysteresis, alternate stable states, basins of attraction and 'regime shifts' will now be discussed.

2.3.1. Hysteresis

In general, hysteresis refers to systems that have memory, that is, the effects of the current input to the system are not just felt at the same instant. Such a system may exhibit path dependence. That is, it may not be possible to follow the same path when returning to the original equilibrium after disturbance. A different path may be followed, which could be longer.

Figure 2.1 shows the graph of elastic hysteresis for a rubber band. If we take a rubber band and add weights to it, it becomes longer as the weights are increased. As we remove the weights it gets shorter but as each weight is taken off, the weights left on there produce a longer length then they did on the way down. This is an example of a simple hysteresis loop – following a different path on the way down from the way back, also known as path dependence.

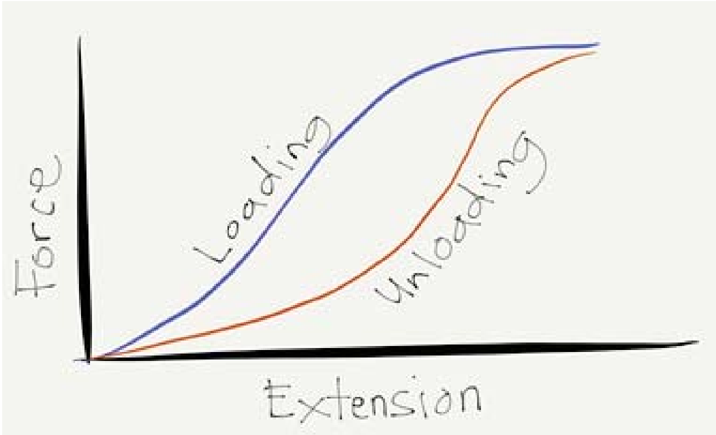


Figure 2.2. Elastic hysteresis of an idealised rubber band

Work on ecological resilience highlights that ecosystems often display hysteresis and that it is often not possible to follow the same path when returning to the original equilibrium after disturbance. Ecologists warn that the path back is likely to be longer due to what is known as the 'humpty-dumpty principle', which states simply: it is easier to break the egg than to put it back together. This translates to the idea that undesirable states may be extremely difficult to move out of, becoming traps that constrain future options.

Reversing environmental degradation at meaningful scales might not be possible in many cases, and the path back, if there is one, is likely to be very different and slower than the one forward. Extinction cannot be reversed by removing hunting pressure or restoring habitat. Many changes simply cannot be reversed. Although this conclusion may seem obvious, there is nonetheless an expectation amongst some people that a pristine wilderness will once more emerge whenever local human pressures are ameliorated.

Some environmental changes such as salinization and desertification are virtually impossible to reverse. Furthermore, most attempts at restoration are too small to be self-sustaining or to account for larger-scale processes. Even large-scale ecosystem restoration, such as the multi-billion USD restoration plan for the Everglades, may or may not be biologically achievable (Doyle and Drew, 2008). No one has ever successfully rebuilt a coral reef coastline, and intuitively such a task is inherently more difficult than restoration of a few hectares of grassland or rebuilding the relatively simple trophic structure of a lake (Hughes et al., 2007). The impetus is not to damage it in the first place.

Hysteresis also relates to the idea of 'alternate stable states', since there may be alternate stable equilibriums for the same variable and parameter values.

2.3.2. Alternate Stable States, Thresholds and Regime Shifts

Studies of interacting populations conducted in the 1960s and 1970s, such as predator prey models and their functional responses to changes in their environment, revealed evidence that natural systems can be thought of as having multiple alternative stable states, multiple stability domains, or multiple basins of attraction (Holling, 1961, Lewontonin, 1969, Rosenzweig, 1971). These models showed that ecosystems could undergo abrupt, dramatic and sometimes catastrophic changes, known as regime shifts (May, 1977). This is closely related to the idea of thresholds in certain variables that can be crossed leading to sudden dramatic shifts in ecosystems or regime shifts, which may be difficult or impossible to reverse given the notion of hysteresis described earlier (Scheffer et al., 2001).

This led to the formulation of resilience as the amount of disturbance that a system can absorb before changing to another stable regime, which is controlled by a different set of functions and processes:

- '[Resilience is] the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behaviour'(Holling and Gunderson, 2002).
- 'Resilience is the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes. A resilient ecosystem can withstand shocks and rebuild itself when necessary' (Resilience Alliance, 2002).
- A resilient system by definition continues to absorb disturbances without undergoing a regime shift (Hughes et al., 2007).
- The capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same structure, function, identity and feedbacks (Walker et al., 2004).

These definitions of ecological resilience echo the conceptualization of resilience as absorbing and recovering from disturbance. The focus of these definitions is on maintaining essentially the same qualitative condition or regime, involving the same identity, structure, functions, and feedbacks. They focus on the stability of a regime, rather than the stability of a single state and thus represent only a shift in scale from the original engineering conceptualization of resilience.

Borrowing visualization and metaphor from non-linear dynamical systems models, each regime is interpreted as a different basin of attraction as shown in Figure 2.3. Each stable state is interpreted as the equilibrium point at the bottom of the basin of attraction. The ball in Figure 2.3 represents the state of the system by characterizing the values of the variables in the model at any given time. Without external disturbance, the ball can be thought to roll on the landscape according to gravity. Given any starting position, it will, over time, roll down into one of the basins shown. The threshold for each basin is defined by the edge of the basin, which, if crossed, will result in the ball rolling into an alternate basin. Displacement of the ball by an external shock could result in the state of the system transitioning into an alternate basin and it may be difficult or impossible to return to the original basin. According to Perrings, 'the measure of a system's resilience in any one local stability domain is the extent of the shocks it can absorb before being displaced into some other local stability domain' (Perrings, 1998). This interpretation of resilience leads to attempts to quantify resilience as a function of points on the boundary of an attractor, which will be discussed in more detail in Chapter 3 on quantitative models of resilience.

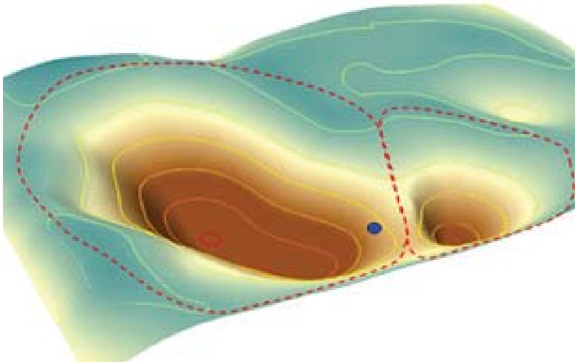


Figure 2.3. Multiple basins of attraction represent multiple regimes, the equilibrium point at the bottom of each basin each represent a different stable state.

This conceptualization of resilience still focuses on stability and recovery. However, acknowledging that multiple possible stable equilibria exist, some of which may be highly undesirable and difficult to get out of, has important implications for policy and management when compared to the assumption of one global equilibrium that the system will certainly return to if pressures on it are reduced.

Since the 1960s, a lot of research has focused directly on establishing the existence of these multiple basins of attraction across a wide range of terrestrial, freshwater and marine ecosystems (Beisner et al., 2003, Stockholm Resilience Centre, 2014). For example, rangelands can undergo shifts from grassland to woodland regimes (Janssen et al., 2004), lakes can undergo shifts from clear water to eutrophic regimes (Carpenter, 2003) and coral reefs can undergo shifts from coral-dominated to algal-dominated regimes (Bellwood et al., 2004).

Figure 2.4 shows the alternate stable states for coral reefs relative to the amount of fishing pressure and pollutants as 'healthy state', 'algal-dominated', 'sea urchin barren' and 'rock'(Bellwood et al., 2004). Each of these alternative stable states is represented heuristically by the ball-in-cup model shown in Section B of the figure. Hughes and Bellwood have demonstrated how overharvesting of tropical herbivorous fishes can make coral reefs reliant on grazing by just a few species of sea urchins that control the biomass of fast-growing fleshy seaweeds. Overfished reefs may harbour large populations of sea urchins, which can erode calcerous substrates, thereby inhibiting replenishment of juvenile corals and locking the system into a new configuration. Many of these thresholds were crossed decades before anyone realized there was a problem by which time transition was inevitable, highlighting that important thresholds can be hidden (Bellwood et al., 2004, Hughes, 1994).

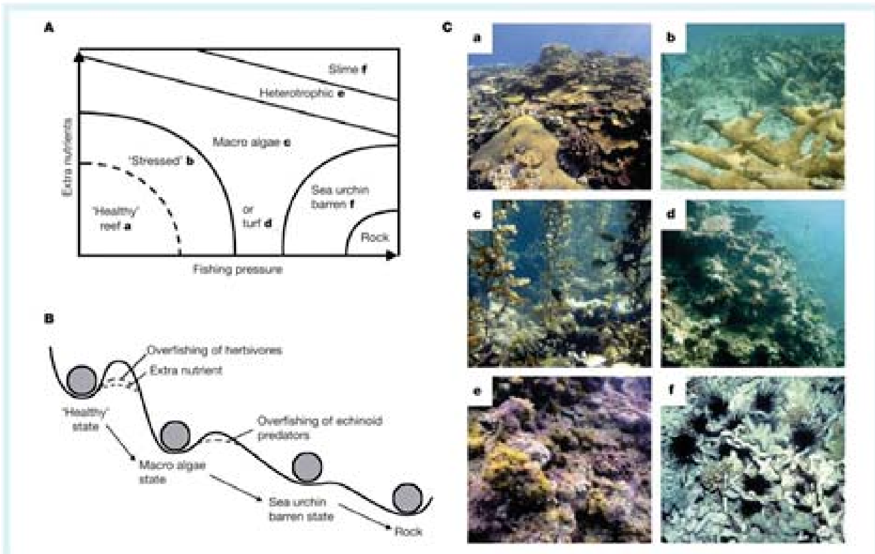


Figure 2.4. Multiple stable states of coral reefs. Source: (Bellwood et al., 2004).

As in the case above, regime shifts are typically associated with the negative impact of human activity: with loss of biological diversity which is associated with a loss of capacity for self-organisation; removing species from food webs, simplifying and changing their structures; accumulation of nutrients, soil erosion, redirection of water flows, and altering patterns of fire (Gunderson and Pritchard, 2002). Such impacts are said to have shifted ecosystems from desirable states into less desirable ones with subsequent impacts on livelihood and societal development (Folke et al., 2004). The combined effects of these pressures make social-ecological systems more vulnerable to changes that previously could be absorbed, and therefore represent a loss of resilience (Folke, 2006).

While the theory of these systems is well understood, whether or not multiple stable states actually exist in nature, or are an artifact of the way these systems have been framed and modeled, is still a hotly debated topic (Schroeder et al., 2005). There are many ecologists who suggest that ecosystems are never in equilibrium and are always undergoing change and flux. According to Carpenter, who has produced a great deal of the evidence for regime shifts in lake ecosystems, 'much ecological thinking is organized around ideas about stability and attempts to understand the variability of ecosystems as departures from a stable condition. In contrast, large-scale field observations, especially long-term ecological research, suggest that ongoing change and variability are the typical condition' (Carpenter, 2003). Even in the face of this, the warning to decision-makers stands – that there is real danger of crossing thresholds, which may be hidden, resulting in catastrophic shifts in ecosystems that are difficult or impossible to recover from.

2.3.3. Desirable and Undesirable States and Basins of Attraction

A great deal of resilience literature is concerned with maintaining desirable states and regimes and avoiding undesirable states or flipping into undesirable basins of attraction:

- 'Learning how to avoid undesirable phase-shifts, and how to reverse them when they occur, requires an urgent reform of scientific approaches, policies, governance structures … An improved understanding of the processes and mechanisms that build or erode resilience is urgently required, in order to predict and avoid undesirable phase-shifts' (Hughes et al., 2010).
- 'Collective capacity to manage resilience, intentionally, determines whether they can successfully avoid crossing into an undesirable system regime, or succeed in crossing back into a desirable one' (Walker et al., 2004).
- 'Governance of resilience will be required to sustain desired ecosystem states and transform degraded ecosystems into … desirable configurations' (Folke et al., 2004).

The focus is on avoiding undesirable regime shifts, for example, from a coral reef to an algal forest and promoting desirable regime shifts like reversing lake eutrophication.

The notion of undesirable versus desirable states, of flipping into undesirable basins of attraction, highlights the normative nature of resilience and raises questions like what is desirable and to whom? Who gets to define what is desirable and beneficial? By this understanding, resilience is value-laden and observer-dependent. Changes in regime that are desirable from the perspective of one group of stakeholders (including non-human stakeholders) might be detrimental to another group. The shift from coral reef to algal forest may look desirable from the perspective of the algae. Hughes acknowledges this normative dimension of resilience: 'Alternate ecological regimes can sometimes be viewed consensually as desirable or undesirable, or conflict may arise among diverse stakeholders (e.g., recreational and commercial fishers or hunters, conservationists, tourists, old and new residents, indigenous groups, etc.) as to which regime configuration is preferable' (Hughes et al., 2007). This raises some very interesting challenges to operationalizing resilience in practice in terms of whose voices will be taken into account and in what way. These issues will be addressed in Chapters 4 and 5.

2.4. Social-Ecological Resilience

There are no natural systems on Earth today that have not been affected by people in some way. Many ecosystems we observe have been thoroughly shaped by human activity throughout history. There are no social systems that exist independently of nature. Natural systems provide the biophysical foundation for all human development. Humans are part of nature not outside of it. Humans are just one species. The term, 'social-ecological system', is designed to capture the meaning of interdependence and co-evolution of human and natural systems.

This is a significant philosophical shift from historical natural science approaches that place humans outside of the domain of ecology, considering human beings a separate issue, to approaches that see humans as part of nature, continuously impacting on it and being impacted upon by it. It reframes the way humans view their relationship with nature and is a key part of 'resilience thinking' (Stockholm Resilience Centre, 2007b, Walker and Salt, 2006).

Some social-ecological definitions echo the understanding of resilience as absorbing disturbance and maintaining specified properties in the face of change. Resilience is defined as:

- 'The capacity of social-ecological systems to absorb recurrent disturbances (...) so as to retain essential structures, processes and feedbacks' (Adger et al., 2005c).
- 'The ability of the [social-ecological] system to maintain its identity in the face of internal change and external shocks and disturbances' (Cumming and Collier, 2005).

These definitions are reminiscent of Walker et al.'s definition for ecological systems as 'the capacity of a system to absorb disturbance and re-organize while undergoing change so as to still retain essentially the same structure, function, identity and feedbacks' (Walker et al., 2004), and indeed Adger is part of the same community known as the 'Resilience Alliance'.

These definitions raise strong questions: what are essential structures, processes and feedbacks? What or whom are they essential to? Who gets to decide what is essential versus what is non-essential and can be sacrificed? Notions of essentialism in the resilience literature are discussed in Section 1.4.1. and practical ways of dealing with the questions of what is essential to whom, and who gets to decide, are provided in Chapters 4 and 5, with further examples in Chapters 6, 7 and 8.

However, many scholars involved in resilience in relation to social-ecological systems increasingly avoid the use of terms meaning staying the same or recovering and prefer the concepts of renewal, regeneration and reorganization following disturbance, adapting as a mechanism for coping with change:

- 'The resilience approach is concerned with how to persist through continuous development in the face of change and how to innovate and transform into new more desirable configurations' (Folke, 2006).
- 'Resilience is the capacity of a system to absorb and utilize, or even benefit from, perturbations and changes that attain it' (Holling, 1973).

It is not always desirable to return to the same equilibrium and disturbance can be an opportunity for positive change. This idea is captured in the Joel Pett cartoon shown in Figure 2.5. Adding the notion of innovating, adapting and benefiting to the conceptualization means that systems do not need to return to the same equilibrium or maintain the same regime in order to be resilient. They can be considered resilient as long as the resulting change is judged to be at least as desirable as the original state or regime. This is important considering the dispute that exists over whether social or ecological systems are ever in equilibrium or undergo constant change.

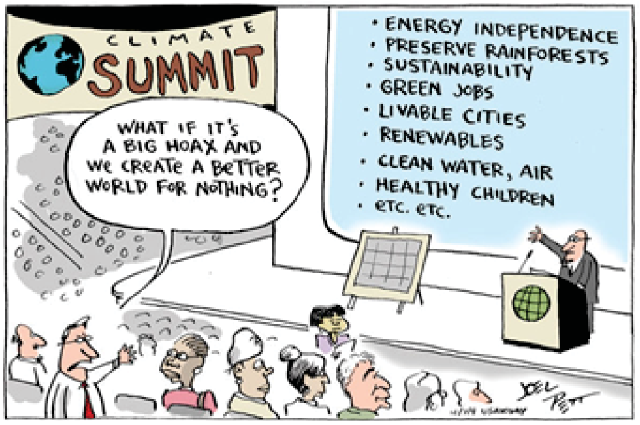


Figure 2.5. Disturbance is an opportunity for positive change. Source: (Pett, 2009).

There are also authors who include all three types of behaviour in response to disturbance in their conceptualization of resilience: absorbing and maintaining, recovering and adapting and learning:

- Resilience, for social-ecological systems, is related to (a) the magnitude of shock that the system can absorb and remain within a given state, (b) the degree to which the system is capable of self- organization, and (c) the degree to which the system can build capacity for learning and adaptation' (Swedish Government, 2002).

2.4.1. Interconnectedness and Holism

According to the Resilience Alliance, resilience grew out of a desire to be holistic, to avoid the oversimplifications and narrow reductionist approaches that led to poor stewardship of human and natural systems and collapse in the past (Walker et al., 2004, Hughes et al., 2007). According to a widely held understanding of the resilience idea, resilience thinking means an effort to 'look at the whole' of an issue (Walker and Salt, 2006, Folke et al., 2010) – that is, to include the entire relevant problem environment in one's definition of a modelling, design or governance problem.

Another important important part of taking a resilience approach is acknowledging the fundamental interdependence and interrelatedness of all things (Walker and Salt, 2006). Many authors have written about panarchy and cross-scale and cross-level effects (Gunderson and Holling, 2002), about the need for interdisciplinarity (Folke, 2006, Brand and Jax, 2007), the interaction of multiple stressors (O'Brien et al., 2004) and the multi-consequentialist nature of any intervention aimed at building resilience (Agrawal, 2011).

There is increasing awareness of the links that exist between physical, social, economic, political and ecological systems at all scales (Gunderson and Holling, 2002). Environmental problems such as climate change, deforestation and biodiversity loss interact with social problems such as poverty and inequitable distribution of wealth both within and between nations (Mikkelson et al., 2007, Adger and Kelly, 1999, Adger et al., 2005a, Ribot, 2009, Midgley, 2000).

This section on Interconnectedness and Holism, and the following sections on Panarchy and Complex Adaptive Systems are included here even though they are not only relevant to social-ecological resilience, and are relevant to resilience more broadly. This is because of the huge significance these concepts have within the social-ecological resilience literature, and because it is helpful for the reader to become familiar with these concepts for the sections that follow in this chapter.

2.4.2. Panarchy

In resilience literature, the term, 'panarchy', is used to describe highly interconnected systems involving of nested sets of adaptive cycles with feedbacks between them across scales. These cross-scale links can occur at all scales, from small to very large scales and vice versa (Hughes et al., 2007). For example, large-scale migration and transport of propagules, such as larvae or seeds, are crucial processes for understanding local trends in the composition of biological assemblages (Nystrom and Folke, 2001, Nystrom et al., 2000). Conversely, when local patches of habitat undergo regime shifts - often due to human activity - the species composition of the propagules they export changes, modifying the larger-scale pattern of connectivity among patches, subsequently affecting livelihoods. Cross-scale interactions can also create abrupt threshold dynamics in intricate ways (Klausmeier, 2001).

Panarchy identifies four basic stages in the dynamics of social ecological systems:

1. Growth or exploitation (r)
2. Conservation (K)
3. Collapse or release (Ω)
4. Reorganization (α)

The adaptive cycle exhibits two major transitions. The loop from r to K, is thought of as a slower, incremental phase involving growth and accumulation. The loop from Ω to α, is thought of as a rapid phase involving reorganization leading to renewal (Holling et al., 2002).

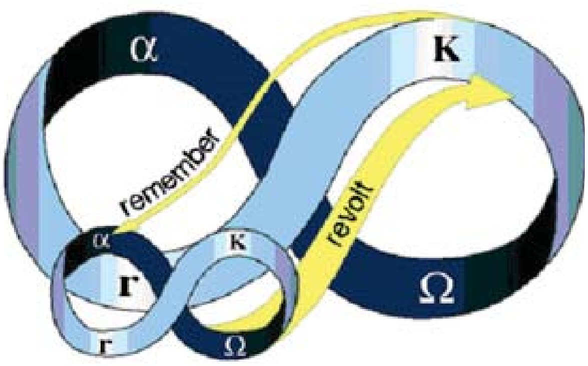


Figure 2.6. Panarchy, adaptive cycles. Source: (Holling et al., 2002).

The theory of panarchy states that larger, slower cycles generally constrain the smaller, faster ones and maintain system integrity, but, during the Ω and α phases, critical cross-scale interactions can operate, particularly 'Revolt' connections, in which an Ω phase collapse on one level triggers a crisis one level up, and 'Remember' connections, in which the α phase of a cycle is organized by a higher-level K phase (Gotts, 2007). These phases of the adaptive cycle are shown in Figure 2.6.

Panarchy and the adaptive cycle are meant as tools for thought. They have inspired work on management of institutions and theories of social change (Holling and Sanderson, 1996, Westley, 2002), resilience of food systems to pressures and shocks (Fraser, 2003, Fraser et al., 2005) historical co-development of landscapes and human societies including conflicts (van der Leeuw, 2000, Redman and Kinzig, 2003, Berkes et al., 2003). The ideas of the adaptive cycle have been applied to innovation in formal organizations and in informal social networks (Hamel and Valikangas, 2003, Martin-Breen and Anderies, 2011).

2.4.3. Complex Adaptive Systems

Social-ecological systems are frequently identified in the resilience literature as complex systems or complex adaptive systems and resilience scholars borrow language from complexity theory by speaking about phase shifts, path dependence, self-organisation, novelty and adaptation, cross-scale and cross-level feedbacks and nested systems with respect to resilience (Cumming and Collier, 2005, Hughes, 1994, Folke, 2006).

These concepts are often described, then illustrated with reference to multiple basins of attraction and examples of their existence in social-ecological systems (Folke, 2006, Bellwood et al., 2004). Non-linear dynamical systems can give rise to extremely complex behaviour, such as multiple stable attractors, but they are not complex or adaptive – they are deterministic in the sense that, once the model is written down, the future behaviour is completely determined and depends only on initial conditions. Although deterministic dynamical systems can generate behaviour that is sufficiently complex to be of interest to resilience studies, they cannot capture key elements of resilience: novelty and adaptation. These concepts are core to systems that evolve; social-ecological systems certainly evolve and hence fall into that category (Martin-Breen and Anderies, 2011).

Nevertheless, the conceptualization of social-ecological systems as complex adaptive systems is important and has practical relevance for management and planning. According to the Stockholm Resilience Centre, 'The complex adaptive systems approach shifts the perspective on governance from trying to control change in resource and ecosystems assumed to be stable, to enhancing the capacity of social-ecological systems to learn to live with and shape change and even find ways to transform into more desirable directions' (Stockholm Resilience Centre, 2007a). There is a significant increase in humility in this approach, which acknowledges it is hard to forecast the future, and suggests the notion of adaptive management to allow us to learn as we go. Adaptive management is discussed in 2.7.1.

While a great deal of the use of complex systems language in the resilience literature is heuristic, metaphorical and partial, complex systems science does relate to the key concepts of resilience theory and does offer a lot to its development. Complex adaptive systems are modeled effectively with agent-based models, and numerous scholars are applying this approach to understanding resilience and these are being used to model resilience (Bonabeau, 2002). Research continues to be conducted into how complex adaptive systems approaches can be applied to understand how systems self-structure over time, how novelty and evolution might be shaped, and when systems will undergo phase shifts (Levin, 1998).

2.4.4. Essentialism in the Maintenance of Features

Essentialism permeates the resilience literature, as demonstrated by the following definitions (repeated from Section 1.4):

- Social-ecological resilience is defined as 'the capacity of social-ecological systems to absorb recurrent disturbances (...) so as to retain essential structures, processes and feedbacks' (Adger et al., 2005c).
- The ability of the system to maintain its identity in the face of internal change and external shocks and disturbances (Cumming and Collier, 2005).

Walker and Holling also talk about 'essential' structures, functions and feedbacks (Walker et al., 2004). This raises strong issues: what are essential structures, processes and feedbacks? What or whom are they essential to? Who gets to decide what is essential versus what is non-essential and can be sacrificed?

Essentialism is the position that entities have some essential nature, which is observer-independent, which is a property of that object in and of itself rather than relational, and which fundamentally makes that object what it is. It is a close relative of naïve realism, which assumes that we perceive objects as they really are and therefore are capable of determining an entity's essential nature and accordingly classifying it.

Essentialism may have been inherited from the Linnaean tradition in the natural sciences. Certainly it seems easier to accept the notion of certain ecosystem processes being essential, than to identify essential social processes. Linnaean taxonomy divides things into classes according to features and it is thought that correct classification is determined by the natural order of the world and not imposed by the taxonomer (Matthews, 2004). Accordingly, from this perspective, the inquirer does not need to worry about 'essential to what or whom'. The act of discovering the 'correct' classification reveals a great deal about the entity and the search for nature's 'true' categories becomes the goal of inquiry. In order for us to operationalize the definitions of resilience above, we need to discover what makes it what it is, its identity, its essential structures, functions and feedbacks, and these need to be maintained. Thus, if we discover what fundamentally makes systems what they are, we are equipped to manage their resilience.

Essentialism is implicit in the ecological literature on resilience in that many ecologists will argue that ecosystems are concrete entities that exist and have specific features that make them what they are; the focus of resilience then becomes the maintenance of these features. Ecology has a clear sense of what makes a coral reef versus an algal forest, or a rainforest versus savannah and contends that coral reefs, algal forests, rainforests and savannahs exist.

There are fundamental incompatibilities between essentialist ideas and the ontology of interconnectedness and systemic approaches that form an important part of the language and conceptual frameworks of the resilience community. Systems and networks are relational, not essential. What things are, they are for an empirical observer, and what these things can do depends on how they are related to other things (Fuchs, 2001). Systems theory and system boundary judgements will be discussed in more detail in Chapter 3. In short, where system boundaries are drawn has a large impact on any inquirer's perception of what makes a system what it is, and system boundary judgements are not given objectively by the structure of reality, they are observer imposed. Acknowledging interconnectedness between social, ecological, political and economic systems across scales – a crucial part of resilience theory as discussed in Sections 1.4.1 and 1.4.2 – makes the setting of system boundaries difficult and potentially highly contentious.

A system is a complex whole, made up of interconnected (potentially heterogeneous) components that interact with each other. Anything can be viewed as a complex whole: an individual, their physical body, an ecosystem, government, bridge, society, tree and so forth (Martin-Breen and Anderies, 2011). Where boundaries are drawn in the process of carving out wholes seems clearer in the case of a tree or an animal than when carving out the boundaries of a social system. Standing on the side of a mountain and attempting to clearly define the boundaries of different ecosystems on the slope, or the boundaries of the broader ecosystem the whole slope is part of, is equally problematic. The same is certainly true of social-ecological systems.

It seems, in the very least, that something exists: resilience tells us that something is highly interconnected, Kant tells us we have no unmediated access to whatever that is, many critical systems thinkers including Churchman, Ulrich and Midgley tell us that we divide up that interconnected stuff in various ways depending on our world view, values and purpose of inquiry (Churchman, 1968, Ulrich, 1983, Midgley, 2000). In summary, systems, their boundaries and their 'essential' structures, functions and feedbacks are value-laden, observer-dependent decisions. The need to overcome essentialism in order to bridge scientific disciplines and achieve genuinely interdisciplinary research outcomes is the focus of Stephen Fuchs volume, 'Against Essentialism' (Fuchs, 2001). This necessitates the methodological considerations for operationalizing resilience discussed in Chapter 5. In practice, involved and affected stakeholders need to negotiate which features of a system need to be maintained and which can change in response to disturbance.

2.5. Social Resilience

Social resilience is often defined as the ability of communities to cope with stresses as they arise:

- 'The ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change' (Adger, 2000b).

- 'Resilience in human societies requires growth in knowledge, communication, wealth and organisational capacity, the resources that enable us to craft what we need when we need it, even though we previously had no idea we would need it' (Wildavsky, 1995).
- 'Resilience is not only about being persistent or robust to disturbance. It is also about the opportunities that disturbance opens up in terms of recombination of evolved structures and processes, renewal of the system and emergence of new trajectories' (Folke, 2006).
- 'Resilience provides adaptive capacity that allows for continuous development, like a dynamic interplay between sustaining and developing with change' (Smit and Wandel, 2006).

These definitions allow space for any of the three types of behaviour mentioned so far in response to disturbance as a way of coping with stress: absorbing, recovering or adapting and benefiting. Wildavsky's understanding of resilience highlights the sense that societies cannot predict or control all of the stresses that might affect them. Being able to cope with things as they arise, even though they were not anticipated or predicted, is an important part of his understanding of resilience. Folke highlights the adaptive dimension of resilience and emphasizes that disturbance is an opportunity for positive change and reorganisation.

The collection of concepts associated with resilience thus far, including regime shifts, multiple basins, thresholds, hysteresis and adaptive cycles have been applied to social systems. Jarred Diamond interpreted the collapse of ancient civilizations in terms of regime shifts in social-ecological systems (Diamond, 2005). Janssen examines the social dynamics of ancient civilizations in terms of regime shifts (Janssen et al., 2003). Scheffer examined the dynamics of public opinion and action in terms of multiple attractors, thresholds and hysteresis. He has shown that in switching to action from being passive, the public will follow a different path from a passive to an active attitude than from an active to a passive one. It take a much greater perception of risk and seriousness of the problem to lead to action in the first place and, once we have an active attitude, we can drop back the seriousness of the problem quite a lot and still have an active attitude before we switch back to a passive attitude (Scheffer et al., 2003). This is shown in Figure 2.7.

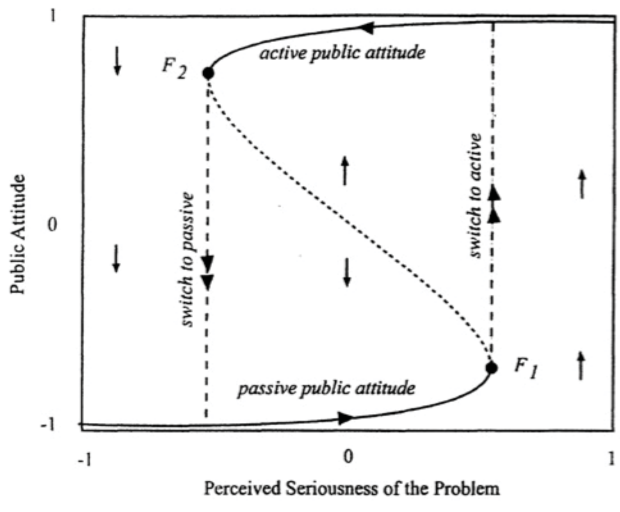


Figure 2.7. Curve showing social hysteresis in public attitude change. Source:(Scheffer et al., 2003).

The idea of becoming trapped in undesirable basins maps well with existing theories of poverty and marginalization, such as poverty traps. It can also be used to interpret draconian regimes such as the Burmese military government (monk protest shown in Figure 2.8). The Burmese example highlights that what is desirable from one perspective might be highly undesirable from another. The Burmese military government has been very effective at maintaining its essential structures, feedbacks and processes in the face of disturbances from cyclones to social movements and national and international protests; an outcome which was clearly undesirable from the perspective of the protesting monks and a great deal of the Burmese population. Depending on your perspective, it is also useful to know how to undermine resilience as well as to build it. This is a system boundary judgment issue which will be discussed further in Chapters 4 and 5. Clearly we do not always want to be locked into the same equilibrium, or basin or qualitative status. Disturbance can be an opportunity for positive change and for new things to happen.

Figure 2.8. Burmese monks protest against the military junta. Source: (BBC News, 2007).

A substantial amount of work has been done on organizational and institutional structures and flexibility for dealing with uncertainty and change (Grumbine, 1994, Danter et al., 2000, Ostrom, 2005, Berkes and Folke, 1998). The concepts of adaptive management and adaptive governance are covered in more detail in Section 1.7.1.

A large amount of resilience literature, particularly relating to social and social ecological resilience, highlights that we cannot predict, still less control, systems or assume them to be stable (Folke, 2006). Thus, they aim to shift policies from those that aspire to control change in systems assumed to be stable, to managing the capacity of systems to cope with, adapt to, and shape change (Berkes et al., 2003). Many authors argue that managing for resilience, as opposed to stability, enhances the likelihood of sustaining desirable pathways for development in changing environments where the future is unpredictable and surprise is likely (Folke, 2006, Walker et al., 2004, Adger et al., 2005c).

2.5.1. Community Resilience

The majority of work on community resilience has been born out of the international development, community development, disaster management and climate adaptation sectors (Vermuelen et al., 2008, Norris et al., 2008, Saavadra and Budd, 2009, Paton, 2000, Jabeen et al., 2010). Accordingly, it has an applied focus. Rather than seeking conceptual definitions in terms of specific modes of behaviour (absorbing, recovering or adapting beneficially), most authors have sought to elucidate the factors that support or undermine the ability of communities to cope with various stressors and define resilience in terms of those factors. For example, consider the UNIDSR definition of community resilience:

- 'The resilience of a community is determined by the degree to which the community has the necessary resources and is capable of organizing itself both prior to and during times of need' (UNISDR, 2007).

This definition does not characterise resilience in terms of mode of response to stress (absorbing, recovering, adapting) but, rather, focuses on resources and capacities.

The applied focus of the community resilience literature involves numerous studies of the response of specific communities around the globe to past and present disturbance, in search of general patterns, seeking to draw out practical and generalizable frameworks for building community resilience. Adger et al. describe the emerging research agenda as 'focused on identifying generic determinants of resilience. [...] These determinants include the social capital of societies, the flexibility and innovation in the institutions of government and the private sector to grasp opportunities associated with change, and the underlying health status and wellbeing of individuals and groups' (Adger et al., 2003).

Some authors have focused predominantly on access and allocation of resources. Poverty undermines community resilience, since lack of access to key assets and capital constrains options for mitigating and adapting to stressors (Allison et al., 2007, Barrett and Swallow, 2006, Prowse and Scott, 2008, Perrings, 2006). Twigg specifies the equitable distribution of wealth and assets and an equitable economy as essential to building community resilience (Twigg, 2007). Nelson et al. find that systems may become less resilient if issues of justice and equity are not given due consideration (Nelson et al., 2007). Similarly, Cutter et al. argue that communities with higher equity are likely to be more resilient, based on an extensive study of communities across eight regions in the United States (Cutter et al., 2010).

Some authors have focused primarily on governance structures, institutions and organisations as a key characteristic of community resilience. Institutions and governance structures play an important role in access and entitlement to key assets, capitals and capacity development opportunities such as education. Jones et al. find 'investments in resource governance are paramount, as the management of natural assets and resources is seen as a key characteristic of community resilience' (Jones et al., 2010). Grothman and Patt emphasize that even communities with large access to resources and strong institutions often still lack adaptive capacity for psychological reasons, such as risk perception and perception of their own capacity to adapt. An example of this is Australia's lack of action on climate change (Grothman and Patt, 2005).

There is a great deal of literature on community organising and community cohesion as a crucial factor underpinning community resilience, particularly community resource knowledge and labour pooling to cope with stressors and achieve positive outcomes. This literature states that disruption of social cohesion reduces people's adaptive capacity, making them less resilient (Adger, 2000a, Adger, 2003, Scoones et al., 1996). This is itself related to the idea of social capital, since social capital increases capacity for collective action and effective management of resources (Ostrom and Ahn, 2003, Pretty, 2003). Social capital extends beyond the boundaries of a geographically collocated group of people. Social capital and associated community organising often extends to multiple levels of the society and even outside of it to other societies globally. Social capital is the web of relationships that helps people to succeed or advance through association (Ritchey-Vance, 2002). Social sources of resilience, such as social capital (including trust and social networks) and social memory (including experience for dealing with change) (McIntosh, 2000, Olick and Robbins, 1998), are essential for the capacity to adapt to and shape change (Folke et al., 2003, Folke et al., 2005).

The literature also highlights the importance of education, knowledge and access to information as key factors underpinning community resilience (Wildavsky, 1995). Community resilience is likely to require understanding of plausible future change and its complexity, knowledge about options to cope with change, the ability to assess options, and the ability to implement interventions (Frankhauser and Tol, 1997). Knowledge can also play a role in ensuring local empowerment and capacity for representation at other levels. The way a community generates, collects, analyses and disseminates knowledge is an important determinant of resilience (Jones et al., 2010).

In the light of the factors mentioned thus far, it seems natural that a thread in the community resilience literature uses traditional indicators of development: access to goods and services, infrastructure, connectivity to markets, social and organisational capital, education, literacy and health as proxies for community resilience (Sherrieb et al., 2010). Some authors have also cited the ability to migrate as an important feature of resilience (Adger et al., 2005b, O Neill et al., 2001).

Jones et al. have defined the key factors underpinning the resilience and adaptive capacity of a community in terms of five overlapping characteristic features: asset base, institutions and entitlements, knowledge and information, innovation, flexible forwarding thinking decision-making and governance; as shown in Figure 2.9. This conceptual framework adds two extra dimensions to those already mentioned above: innovation and flexible forward-thinking institutions.

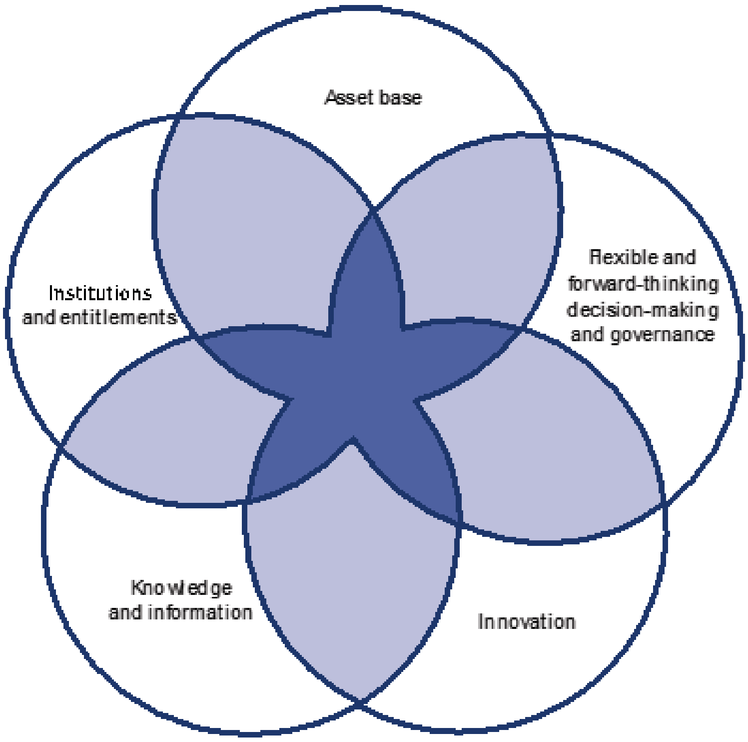


Figure 2.9. Characteristics of resilience and adaptive capacity at community level. Source: (Jones et al., 2010).

Some authors emphasise anticipating the future: Jones et al. include forward-looking as one of the factors underpinning resilience, Hodgson defines a resilient community as 'one that takes intentional action to enhance personal and collective capacity to sustain the good life in the context of turbulence and disruption to its optimum living arrangements' (Hodgson, 2008). Other authors deliberately emphasise the opposite, that, given that communities cannot hope to anticipate all of the sources of change that affect them, they are resilient if they can cope with unanticipated challenges: 'the capacity to cope with unanticipated dangers after they have become manifest' (Wildavsky, 1988).
The International Federation of Red Cross and Red Crescent Societies have defined the following characteristics of community resilience (International Federation of Red Cross and Red Crescent Societies, 2012):

- Be knowledgeable and healthy (have the ability to assess, manage and monitor risks)
- Be organised (have the capacity to identify problems, establish priorities and act).
- Be connected (have relationships with external and internal actors that can offer support, including family, friends, faith groups and government).
- Be endowed with strong infrastructure and services (have strong housing, transport, power, water and sanitation systems. Have the ability to maintain, repair and renovate them).
- Have access to economic opportunities (have a diverse range of employment opportunities, income and financial services).

- Manage their natural assets and resources (have the ability to protect, enhance, maintain and mobilise them).

These frameworks echo the Wildavsky definition of resilience in terms of 'growth in knowledge, communication, wealth and organisational capacity, the resources that enable us to craft what we need when we need it, even though we previously had no idea we would need it' (Wildavsky, 1995). This understanding leads to a natural parallel between resilience and capacity development (Helfgott, 2008).

Many studies dive directly into the task of developing community resilience to various stressors without critical reflection on what community is. Midgley and Ochoa-Arias show that different political and philosophical traditions give rise to very different visions of community associated with different system boundary judgements (Midgley and Ochoa-Arias, 1999). These different visions of community shape very different approaches to intervention for building resilience, from individual 'preparedness kits', to state-based support structures, NGO-based development, privatisation and market-based development, to community organising and subtly different combinations of all of the above types of approach.

The boundaries of a community are extremely hard to define. While some researchers address community as any geographically co-located group of people, others acknowledge the importance of ties with people outside of such a boundary through family, friendship, professional, interest, ethnicity, or other relationships or sources of identity. There are almost infinitely many ways to define community. Midgley covers some important dominant views: western liberalist, communitarian, welfarist and Marxist.

Western liberalist traditions have their philosophical and political underpinnings in the work of Mill, Locke and Kant (Mill, 1859, Locke, 1689, Kant, 1787). The common aspect of these diverse and prolific authors is their focus on the individual as an irreducible moral and rational agent. This paradigm gives rise to a focus on the rights of individuals, and frameworks for protecting the individual from the tyranny of the collective, keeping the state in check and accountable. Accordingly, these traditions often emphasise individual capacity development and individual preparedness (for example 'preparedness kits') rather than focusing on community organising or state-based support structures. There is a link between liberalist and capitalist theories of capacity development that strives to create market access and value-chain development as an approach to building personal wealth and community resilience.

Communitarian cultures focus on the responsibility of individuals to the community rather than the rights of individuals. In communitarian cultures, such as the Wantok system of Papua New Guinea, membership of community is not voluntary as it is in western liberal visions, and involves a complex web of reciprocity obligations. Community resilience work arising from communitarian positions emphasize community organizing, community empowerment and community ownership over decision-making processes and service and resource provision.

A significant characteristic of the Welfare State is the public provision of services to those who are deemed to be disadvantaged or in need in society. Resilience building activities from a welfarist perspective are primarily focused on capacity development of state based agencies and partnerships between the government communities. They may also support the promotion of community involvement in the planning and management of state-based services in order to enable communities to have a voice in decision-making and increase the efficacy of service provision.

Marxist theories highlight that wealth inequality is no accident and raise issues of structural injustice as a result of capitalist systems that promote the accumulation of wealth in the hands of the few (Marx, 1887). Because capitalism is now a global phenomenon, it contributes to massive global inequalities where currently the 85 richest people in the world personally have the same wealth as the entire lower 50% of the global population (Credit Suisse, 2013). For those who believe that equality is an ideal worth striving for, and that capitalism is part of the problem, market-based approaches to capacity development and other neoliberal approaches such as privatisation of goods and services, globalisation of markets and so forth are likely to be mistrusted. In general, interventions influenced by Marxist theories are less focused on mechanisms for the development of personal wealth (and the promise of trickle-down) and more focused on development of shared wealth. Interventions for building community resilience influenced by Marxist paradigms share some aspects with the welfarist paradigm in terms of redistribution of wealth and social safety nets, and with communitarian approaches, which focus on social responsibility. Interventions based on facilitating community organising, common equal ownership, cooperatives and worker groups are consistent with this paradigm.

2.5.2. Disaster Resilience

The term, 'disaster', refers to events causing widespread destruction and distress with sudden onset. Though long-term progressive climate change may have disastrous consequences, it is not considered a disaster as such. Disaster resilience has humanitarian foundations in the work of government and non-government organisations concerned with helping individuals and societies to cope with trauma, shock and disaster. It makes contextual sense that much of the literature on disaster resilience focuses on absorbing or recovering from disturbance. This sense is captured in the UNISDR definition of resilience:

- 'The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. Resilience means the ability to "resile from" or "spring back from" a shock. The resilience of a community in respect to potential hazard events is determined by the degree to which the community has the necessary resources and is capable of organizing itself both prior to and during times of need' (UNISDR, 2007).

This definition makes reference to the maintenance or recovery of 'essential, basic structures and functions'. For a discussion of essentialism, see Section 2.4.4.

'Faced with famine, an epidemic of acutely fatal infectious disease, or a natural disaster, the humanitarian response is geared towards preventing death or permanent disability'

(Martin-Breen and Anderies, 2011). The International Committee of the Red Cross and Red Crescent is quite specific in that its goal is to reduce and prevent morbidity and mortality (International Federation of Red Cross and Red Crescent Societies, 2004). Yet, to prevent death and disability, one might need to overexploit resources to provide food and shelter, or to use antibiotics in a way that might increase the chance of resistant infections in the future. It is often the case that actions taken to cope with an immediate need often undermines resilience to future disasters and stressors. There is often disconnection between measures taken to promote resilience to disasters and longer-term social, ecological, social-ecological or community resilience.

Another important aspect of disaster resilience is that it can be highly differentiated across groups within society and some groups are more or less resilient to different types of disturbance (Buckle et al., 2000). Vulnerable social groups, such as the elderly, children, women, or the economically disadvantaged, may have fewer resources available to cope with disaster (Allenby and Fink, 2005). According to Oxfam 'disasters, however "natural", are profoundly discriminatory. Wherever they hit, pre-existing structures and social conditions determine that some members of the community will be less affected while others will pay a higher price' (Oxfam International, 2005).

To address the disconnect between disaster response and longer-term resilience, many government and non-government organisations now consider it a priority to strengthen the resilience of communities on an ongoing basis rather than post-hoc following particular events, and are addressing this through research, policy, education and program development, as well as in crisis management initiatives. For example, the UNISDR Hyogo Framework focuses on development of community resilience in terms of resources, education, health and institutions as well as crisis response training (UNISDR, 2005). In Australia, the Council of Australian Governments (COAG) adopted a whole-of-nation resilience-based approach to disaster management to improve Australia's capacity to 'withstand and recover from' disasters and emergencies (Council of Australian Governments, 2009). During the decade since 9/11, in these sectors resilience became 'unbiquitous as an operational strategy of emergency preparedness, crisis response and national security' (Walker and Cooper, 2011). The measures taken to build resilience match the categories covered in Section 1.5.1 from individual preparedness kits to community organizing to state-based service provision and so forth, depending on the framework adopted and the political and philosophical position of the agencies involved. Until resilience has been built up enough, difficult choices between present urgency and long-term resilience and sustainability are still being made.

2.6. Psychological Resilience

In the field of psychology, resilience is defined as the capacity of individuals to cope with adversity without maladaptation or psychopathology (that is without showing negative effects) or to 'bounce back' to a previous state of normal functioning, or to undergo 'post-traumatic growth' or 'steeling effects' where the experience of adversity leads to positive adaptation and outcomes for the individual as summarised by the idiom, 'whatever doesn't kill you makes you stronger', much like an inoculation gives one the capacity to cope well with future exposure to disease (Masten, 2010, Ungar, 2004, Cicchetti and Blender, 2004).

There is, unfortunately, little consensus about the definitions of 'resilience, 'adversity', 'positive adaptation', 'positive outcome', and so forth, even within single sub-disciplines such as child-development (Martin-Breen and Anderies, 2011). This resilience literature shares the three modes of behaviour in terms of absorbing, recovering and adapting and benefiting to be found in other disciplines.

As in the case of the community resilience literature above, the study of psychological resilience has focused on detecting the determinants of the phenomenon, in this case predominantly psychosocial determinants (Cicchetti and Blender, 2006). The studies are usually focused on those who have faced significant adversity, or those in highly vulnerable situations. Examples include the sociologist Antonovsky's study of adults who survived concentration camps (Antonovsky et al., 1971), or Klasen's study of former Ugandan child soldiers (Klasen et al., 2010).

The psychological resilience literature refers to 'risk factors', that is, circumstances or characteristics that increase the likelihood of an individual developing an emotional or behavioural problem in response to hardship (Keogh and Weisner, 1993). Prior to the emergence of resilience approaches in psychology, it had been thought that individuals who were subject to multiple risk factors, for example, born into poverty, with alcohol and drug abusing parents, would have adverse developmental and life outcomes, and that those few individuals who were able to thrive in spite of such risk factors were anomalies. Much research focused on assessing risk factors, stressful life events, disabilities, symptoms and disorders (Masten, 2001).

Research into resilience showed, to the contrary, that large numbers of high-risk individuals were able to cope well and even flourish in adversity, that those individuals shared many characteristics, rather than being anomalies. People exhibit far more neuro-plasticity, emotional and behavioural and adaptive capacity than previously thought, and are influenced dynamically by various characteristics of individual psychology and the environment (Cicchetti and Blender, 2006). Studies to identify the characteristics that underpinned resilience to adversity revealed that these characteristics, referred to as 'protective factors', are not themselves extraordinary but very ordinary (Masten, 2010). A short list of protective processes (individual, family, community and culture) that account for human adaptation and resilience is given below (Masten, 2010):

- Positive attachment bonds with caregivers.
- Positive relationships with other nurturing and competent adults (ability to recruit caregivers when family members are absent or abusive).
- Intellectual skills (integrated cognitive systems of a human brain in good working order).
- Self-regulation skills (self-control systems and related executive functions of the human brain).
- Positive self-perceptions; self-efficacy (mastery motivation system – adaptive behaviour is supported by a system of 'mastery motivation', whereby we experience pleasure in agency, or being effective in the world).

- Faith, hope, and a sense of meaning in life (meaning-making systems of belief).
- Friends or romantic partners who are supportive and prosocial.
- Bonds to effective schools and other prosocial organizations (sociocultural systems).
- Communities with positive services and supports for families and children (sociocultural).
- Cultures that provide positive standards, rituals, relationships, and supports (sociocultural).

Note that most of these crucial characteristics are personal, familial and community-based rather than external. Research shows that support services that came from outside the community tend to be far less effective than those that the community already has (Luthar and Cicchetti, 2000). Programs that foster existing relationships and support structures in families and the community are far more effective than 'coming to the rescue' from outside the community when acute adversity strikes. For example, children of depressed parents show better outcomes when they understand the nature of their parent's illness (Luthar and Cicchetti, 2000). Strength-based School Counselling (SBSC) successfully ameliorates problems by promoting existing competences and developing a sense of agency and mastery (Masten, 2010). Even in the most high-risk situations, there usually are some existing mechanisms of resilience as identified above (Martin-Breen and Anderies, 2011).

The key message is that resilience is everywhere, and policy that respects those at risk, rather than tries to control them, can significantly affect positive outcomes. In the field of psychology, resilience thinking moved both understanding and intervention beyond deficit-based models to positive frameworks, or strength-based approaches for change that can build on what exists and 'take advantage of existing adaptive systems in human development and social systems' (Masten, 2010). This conclusion is supported by the work of Ungar, Rutter and Zautra (Ungar, 2004). The same message applies to international development work with communities aimed at building resilience and adaptive capacity and this is the topic of a publication by the author (Helfgott, 2008). The general relationship between resilience and strength-based approaches to capacity development will be discussed in Chapter 5.

2.7. Related Concepts

2.7.1. Adaptation

Like resilience, the concept of adaptation has been applied to numerous subjects, and has been used with varying meanings, and different degrees of rigour, across disciplines, sectors and social worlds:

- Darwin first formally used the term in 1859 to describe changes in an organism that occur, through variation, inheritance and selection, in order to increase the fit of the organism with its environment (Darwin, 1859). His definition is used rigorously in evolutionary biology.
- Dawkins extended Darwin's principles of variation, inheritance and selection to apply to adaptive change in all open, complex systems, including culture (Dawkins, 1983).

- Complex systems literature defines adaptation as 'a process where the behaviour of the system changes such that there is an increase in the fit, and therefore the mutual information, between the system and a potentially complex and non-stationary environment' (Ryan, 2007).

- Tawileh and McIntosh define adaptation in business more simply as 'Undergoing change to reflect changes in the surrounding environment' (Tawileh and McIntosh, 2008).

- Within food systems and food security, literature adaptation has been referred to simply as 'doing things differently' and can serve to either increase or decrease fit with a changing environment (maladaptation) (White, 2010).

- The IPCC defines adaptation in the context of climate change, as 'adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. This term refers to changes in processes, practices, or structures to moderate or offset potential damages or to take advantage of opportunities associated with changes in climate" (IPCC, 2007).

While some of the illustrative definitions above apply to biological organisms and others refer to socio-cultural, socio-economic, social-ecological or other types of complex systems in general, the common thread across all definitions is that they refer to a change in some aspects of the subject that happens in response to signals in its environment. This response can be conscious/intelligent or unconscious/ automated/self-organising; proactive or reactive. Some definitions are specific about what types of aspects can change (structure, function and feedback) while others are not, some specify increased fit with the environment while others just specify change. Adaptation is used as both a noun to describe the change that has occurred, and a verb to describe the process of change. When adaptation occurs across generations at a population level, we say that the system evolved.

Ryan highlights that there are three essential functions for an adaptive mechanism: 'generating variety, observing feedback from interactions with the environment, and selection to reinforce some interactions and inhibit others. Without variation, the system cannot change its behaviour, and therefore it cannot adapt. Without feedback, there is no way for changes in the system to be coupled to changes in its environment. Without preferential selection for some interactions, changes in behaviour will not be statistically different to a random walk. […] The adaptive system does not need to understand the system dynamics of its environment to adapt. Stimulus response interactions provide feedback that modifies an internal model or representation of the environment, which affects the probability of the system taking future actions. […] From an information-theoretic perspective, variation decreases the amount of information encoded in the system, while selection acts to increase information. Since adaptation is defined to increase mutual information between a system and its environment, the information loss from variation must be less than the increase in mutual information from selection' (Ryan, 2007).

Ryan defines first-, second- and third-order adaptation. First-order adaptation involves specified mechanisms for generating variety and for sensing feedback and adapts by changing only the probability of future actions. Second-order adaptation is the case where adaptation is applied to the adaptive mechanism itself to improve the way variety is generated, to adapt the way feedback is observed or to change the way selection is executed (Grisogono, 2005). If an adaptive system contains multiple autonomous agents, a third-order adaptive process can use variation, feedback and selection to change the structure of interactions between agents (Ryan, 2007).

Analogous mechanisms can be designed to facilitate adaptation of social-ecological systems to environmental change through learning, evolving, cultural, organisational and institutional change. The definition of adaptation depends on fitness for purpose. Again, this raises the issue of whose purpose and whose vision. In this case, fitness is not determined solely by ability to survive and propagate but depends on the definition of purpose, which is an abstract concept, defined differently by different stakeholder groups and which itself can evolve over time.

Adaptability and adaptive capacity both refer to the ability of a system to adapt. According to the discussion above this will relate to ability to generate variety, ability to perceive feedbacks from the environment and to select options that are appropriate in context. In social and social-ecological systems this will relate to the types of factors identified by Jones et al. above: asset base, institutions and entitlements, knowledge and information, innovation, flexible forwarding thinking decision-making and governance (Jones et al., 2010) as well as factors such as perception of risk and willingness to change (Grothman and Patt, 2005). The Resilience Alliance defines adaptability and adaptive capacity as synonymous and 'the capacity of a social-ecological system to manage resilience in relation to alternate regimes' (Resilience Alliance, 2002).

It is briefly noted here that, within the global environmental change community, the term adaptation has been largely co-opted to mean adaptation to climate change rather than adaptation to any stimuli in its more general sense.

To build adaptive capacity, Ryan suggests reorganising top-down design, devolving autonomy and increasing independence to provide sufficient fine-scale variety based on supported contextual innovation. Once variety is available, the next phase is boosting the capacity of the system to track changes in the environment and selecting wisely could improve system performance according to local definitions of purpose (Ryan, 2007).

This fits very well with the notion of adaptive governance touted in environmental management under an appreciation that 'ecosystems are complex adaptive systems that require flexible governance with the ability to respond to environmental feedback' (Olsson et al., 2004). Adaptive governance has the following defining characteristics:

- Multiple self-organising groups overlapping: with each other, at different scales, with formal institutions.
- Incorporating knowledge from different disciplines, sectors and social worlds (for example, both scientific and traditional knowledge).
- All learning organisations.
- Not necessarily formal structure.

- Adjusting strategy, policy and action based on continuous monitoring and evaluation and continuous learning.
- Involvement of planners, decision-makers and affected citizens.
- Highlights the role of relationships, social capital and trust.

2.7.2. Vulnerability

Resilience and vulnerability are not only different but related concepts, they also represent different but related research communities, with differing but related approaches to understanding the response of systems to change. Though both are now interdisciplinary, the resilience and vulnerability communities have their dominant origins in ecological and social sciences respectively. These differences in origin contribute to differences in approaches.

Vulnerability is frequently defined as 'susceptibility to be harmed', which depends on a combination of exposure and negative sensitivity to disturbance (Adger, 2006). It is also often thought of as inability to cope with disturbance, which is a loose antonym for resilience, since resilience relates to an ability to cope with disturbance whether through resistance, recovery or adaptive capacity.

The vulnerability research community is related to the international development, and disaster preparedness and response communities. Whereas the applied resilience studies described in Section 2.5 focused on identifying the factors that underpin resilience (ability to cope without adverse effects), most vulnerability studies are applied studies that focus on the factors that underpin vulnerability (inability to cope without adverse effects). Vulnerability assessment frameworks are usually 'problem-based', seeking to diagnose the sources of weakness in order that these be targeted in development of disaster preparedness interventions. Vulnerability research is associated with questions of marginalisation and justice that do not occur so as explicitly in the resilience literature (Adger, 2006).

2.7.3. Transformability

Transformability is defined as 'the capacity to create a fundamentally new system when ecological, economic, or social structures make the existing system untenable' Walker et al. (2004). What differentiates transformation from adaptation is subjective and depends on what is considered fundamental change by those involved in framing the system. How much change of which aspects of the system can occur before relevant stakeholders and experts would say that it has become a different system – it has transformed. Walker et al. state that transformation involves changing the fundamental nature of the original system, such that the original system ceases to exist and a new one is created (Walker et al., 2004). Note that most of the social-ecological literature on this topic does not deal critically with essentialism, system boundary judgements; systems are assumed to be concrete entities the boundaries and fundamental nature of which are given objectively and unproblematically by the structure of reality, as discussed in Section 1.4.4. Many scholars refer to resilience as the maintenance of 'essential' structures, functions and feedbacks, and state that transformation occurs when these essential aspects no longer exist: Walker et al. refers to the maintenance of essential structures, functions and feedbacks in ecosystems (Walker et al., 2004), Adger also refers to maintenance of essential structures and functions for social systems (Adger, 2000b), others refer to the maintenance of specific properties or values of properties (Majer, 1990), others refer to maintaining certain states (Beisner et al., 2003). Across the literature, it seems that anything can change but the identity of the system. Depending on who is defining the system, the identity – that is what makes the system what it is from the perspective of that observer – may depend on ranges of values of certain variables (for example, perhaps something is not a coral reef any more if there is no coral, or not a forest any more if there are less than a certain number of trees), properties, states, functions, structures or dynamical feedbacks. Cumming et al., in fact, propose a definition of resilience as 'the ability of the system to maintain its identity in the face of internal change and external shocks' (Cumming et al., 2005). Essentially transformation begins where resilience ends, when something is no longer what is was, it has transformed. Note that identity itself could potentially be a dynamic concept.

2.8. Conclusions

Resilience can be described as a boundary object (Brand and Jax, 2007). Boundary objects are concepts that are loosely structured in common use and only obtain strong structure and meaning in a particular context. They are flexible, interpreted differently in different disciplines, sectors and social worlds, but have enough common substance to be a recognizable means of translation and can thereby facilitate cooperation (Star and Griesemer, 1989).

Boundary objects are attractive since they are valuable to multiple groups and allow cooperation without consensus about detailed aims or interests (Bechky, 2003). Consider for explanatory purposes a related boundary object: 'sustainability'. Sustainability has allowed groups with seemingly opposing values or goals, such as ecologists and economists, to find a common ground and language to work together for the needs of future generations (Brand and Jax, 2007). According to the UNEP, the concept of sustainability has helped to reconcile contrasting interests of industrial and developing countries (United Nations Environment Program, 2002).

The danger is that this is achieved through manipulation of the term, and co-opting of the sustainability agenda. Sustainability is so highly diluted and unclear and, in practice, has been reduced to a listing of any societal objectives any agent happens to think important. Sustainability and sustainable development have become catchwords that enable different scientific disciplines or social groups to justify their particular interest with respect to an accepted and ethically legitimated societal goal (Ott, 2003).

To a degree, resilience has suffered a similar fate during the past decades, and this maybe part of the political success of the concept – its nature as a boundary object allows people to do what they were already doing or want to do, call it resilience and accordingly gain legitimacy, funding and publications. Its nature as a boundary object may thus even hide conflicts and power relations when different persons agree on the need for resilience while, in fact, meaning different things by it. According to Brand and Jax: 'Even though increased conceptual vagueness can be valuable to foster communication across disciplines and between science and practice, both conceptual clarity and practical relevance of the concept of resilience are critically in danger' (Brand and Jax, 2007).

The inherent conceptual pluralism extant in the field of resilience is problematic for anyone trying to operationalize resilience and certainly for multi-actor and cross-scale resilience planning and decision-making. However, acknowledging the interconnectedness of social, economic, political and environmental systems across scales and levels, taking into account cross-scale and cross-level interactions, and striving towards holism are fundamental aspects of the resilience approach. Thus, a way to clarify resilience across disciplines sectors and social worlds is critically needed.

Towards this end, it is possible to pull out the common threads amongst all of the different understandings of resilience described above. Across all definitions, resilience relates to the response of a system to disturbance or change, whether that disturbance is sudden and shocking or more gradual.

Each definition describes one or more of three types of behaviour possible when a system is subjected to disturbance.

1. Absorb the disturbance and maintain the same original 'state'/certain values of key variables/properties. Those concerned with this type of behaviour tend to describe resilience in terms of the maximum amount of disturbance a system can absorb before changing to a different state. It is often used by people in the risk and security sectors and some engineers. I would call this type of behaviour robustness.

2. Recover from the disturbance, and return to the original 'state'. Those concerned with this type of behaviour tend to be concerned with the time it takes to recover, whether or not the same path is followed back, whether there is hysteresis and so forth. It is often used by those involved with disaster recovery. Many ecologists refer to resilience as a combination of types 1 and 2 behaviour. I would call this stability, since the behaviour around a single equilibrium point has been called stability for around 400 years in mathematics.

3. Adapt as a result of the disturbance and change to a different 'state', which is at least as desirable as the original state. There are those in the resilience community who highlight that it is not always possible or desirable to return to the same equilibrium and who highlight that disturbance can be an opportunity for positive change. This third type of behaviour focuses on adaptive capacity and is often used in combination with the other two by those concerned with human development and SESs.

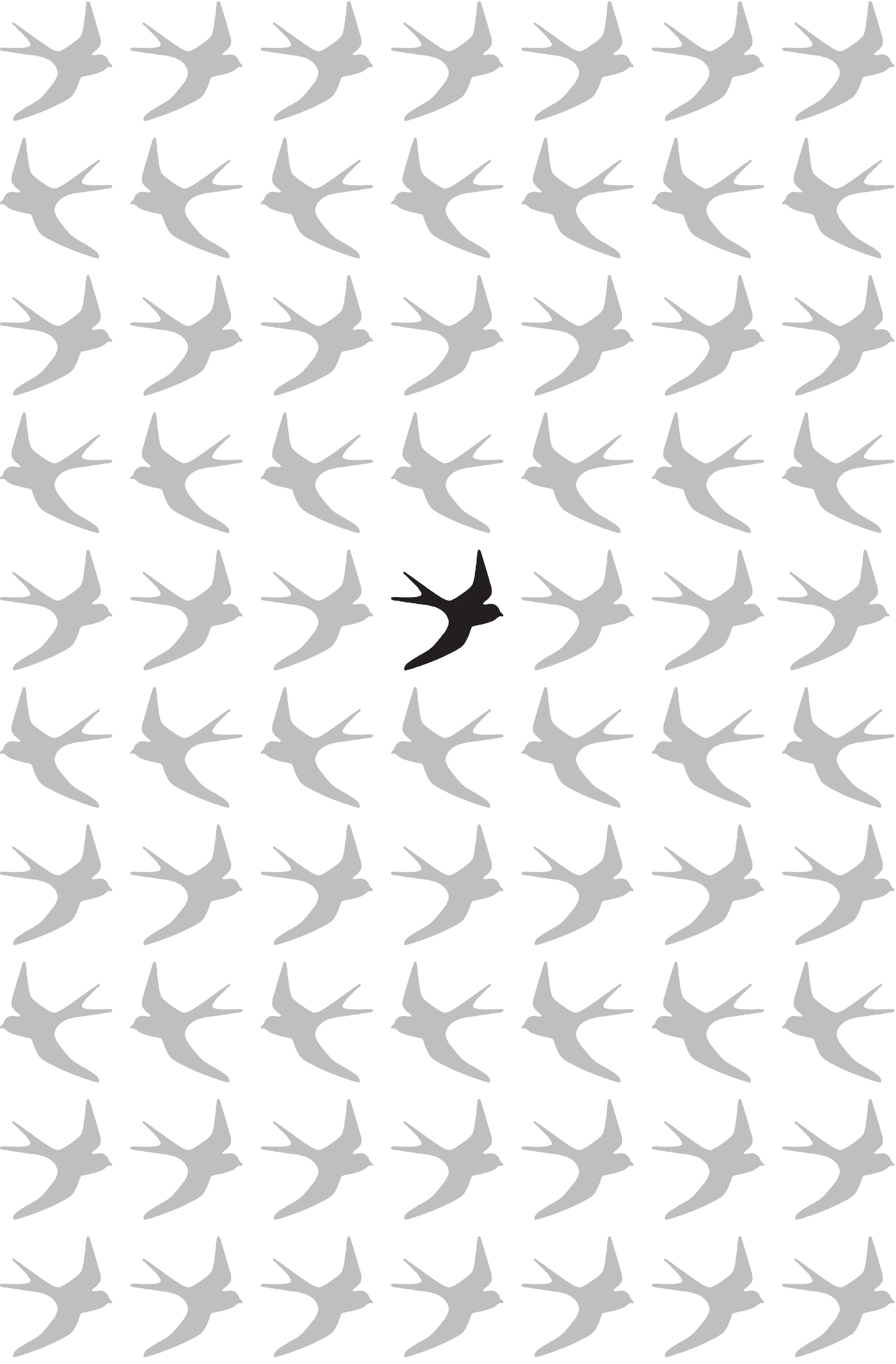
When a system is subjected to disturbance, it can either stay in the same state or not; if it does not stay in the same state it can either return or not; if it does not return, the question is do we like where we end up at least as much as we started – is the system in a more desirable or less desirable state.

Different sectors each have their reasons, which make sense in their particular context of application, for adopting a particular understanding of resilience and there may never be one globally accepted defintion. In order to communicate and collaborate in interdisciplinary, inter-sectoral and inter-agency settings, it has been useful to adopt a loose definition of resilience as the capacity of a system to cope with change by any of the means listed above – because these are all strategies for coping with change and avoiding transition to an undesirable state. Including all three types of response is consistent with Holling's original seminal definition of resilience as the capacity of a system to absorb and utilize and possibly even benefit from disturbance.

At the same time, we must acknowledge that there are trade-offs between these types of behaviour. For example, building robustness can decrease flexibility and adaptive capacity. Consider the example of Gouldburn Broken Catchment in Australia. Gouldburn Broken Valley is thought of as the food bowl of Australia. Over the twentieth century deep-rooted native vegetation was cleared and large-scale irrigation systems were set up to handle water shortages. The water table has risen as a result of the clearing. The area now experiences increased rainfall and the capacity of the system to cope with this has been reduced and, as such, is subject to waterlogging and flooding. The changes made to the system to increase robustness to drought have led to increased vulnerability and lack of ability to cope with flooding. Furthermore, reversing these changes is not easy - replacing deep-rooted native vegetation takes a very long time, while soil salinisation due to the rising water table has caused irrevocable damage and many of those plants simply can't be put back (Eakin et al., 2009).This example highlights the importance of the type of disturbance under consideration and also the importance of time frame.

If I have given the impression so far that there has been a progressive expansion to encompass more of these elements from robustness to stability and recovery and then to adaptability, that is not the case. There has not been a linear development and different sectors have not matured in the same way. All three types of behaviour are still currently in use in isolation and in combination under the name of resilience.

In any given situation, it will be necessary to clarify what is meant by resilience to those involved, and which types of behaviour are relevant to analysis of resilience. This comes down to understanding the boundaries of the system of interest, relevant disturbances, which aspects of the system can change, in what ways and how much for us to call the behaviour resilience, adaptation, vulnerability or transformation, from the perspective of relevant stakeholders and experts. This raises some very interesting challenges to operationalizing resilience in practice.



3.

Mathematical Frameworks for Resilience

3. Mathematical Frameworks for Resilience

3.1. Mathematical Frameworks for Resilience

The review in the previous chapter demonstrated that, while resilience is a boundary object used with different meanings by different disciplines and sectors (Brand and Jax, 2007) and there is inherent pluralism in the field (Folke, 2006, Martin-Breen and Anderies, 2011), it is possible to pull out common threads. Across all disciplines, sectors and social worlds, resilience relates to the response of a system to disturbance or change, whether that disturbance is sudden and shocking or more gradual. Thus, attempts to quantify resilience will involve measurement of system response to disturbance or change, either directly or through measurement of proxies.

When a system is subjected to disturbance, there are only three possible outcomes: it stays in the same state, it does not initially stay in the same state but returns somehow, or, it does not stay in the same state and does not return, but goes somewhere else. Each definition in the resilience literature describes one or more of the following three types of behaviour:

1. Robustness: absorbing the disturbance and maintaining the values of certain variables/ properties;ability to resist change.
2. Stability/Recovery: recovering from the disturbance and returning to the original values of certain variables/properties.
3. Adapting and benefiting: adapting as a result of the disturbance and moving to a new state that is at least as desirable as the original, potentially more so.

If a system is able to withstand disturbance,it will be called resilient; if a system is able to recover from disturbance it will be called resilient;if a system is able to improve following disturbance it will be called resilient.The only response to disturbance that is not considered resilient is when the system changes to an alternate state that is less desirable than where it was prior to the disturbance.

Many types of mathematical apparatus have been applied to the quantification of resilience, including stochastic models(Drury and Lodge, 2009, Bradley et al., 2012), graph theory(Berche et al., 2009, Doyle et al., 2005, Leu et al., 2010), network analysis (Dorbritz, 2011, Ercal and Matta, 2013), fuzzy inference (Chan and Wong, 2007, Heaslip et al., 2010, Freckleton et al., 2012), fuzzy cognitive maps(Kok, 2009, Wildenberg et al., 2014, Gray et al., 2013), dynamical systems (Walker et al., 2004, Bruneau et al., 2003, Cimellaro et al., 2010) and bifurcation theory (Lenton et al., 2009, Scheffer, 2010, Ludwig, 1997), control theory (Vugrin et al., 2009) and viability theory(Martin, 2004, Deffuant and Gilbert, 2011, Rougé et al., 2013), information theory(Tamvakis and Xenidis, 2013) andindicators and indexes(Sherrieb et al., 2010, Cutter et al., 2010, Chan and Wong, 2007, Green and Bellwood, 2009, Cabell and Oelofse, 2012).

Quantitative models of resilience are as diverse and multitudinous as conceptual ones. Nevertheless, the framework described above in terms of three types of behaviour in response to disturbance is useful for making sense of the quantitative resilience literature. Essentially, the various authors, using a wide range of approaches, have sought to measure robustness, stability/recovery and adaptive capacity directly or through identifying and measuring proxies for these capacities.This chapter seeks to review and synthesize existing quantitative frameworks for resilience extant in literature and practice. As with the previous chapter, it is not possible to cover every single attempt to measure resilience in the literature, as that would take many volumes and years, if even possible, given the proliferation of material in many disciplines and sectors. What it does is provide a representative spectrum of the ways resilience can be measured, provides a meta-framework that any measurement practice can be situated within, critiques existing approaches and works towards a coherent mathematical framework for the measurement of resilience.

3.2. Classical Representation Conventions

While the published literature on quantification of resilience omits the distinctions provided in classical mathematical definitions of system property and system state, types of stability, stability of property versus stability of state, these definitions are covered here for the clarity they provide in making sense of existing quantitative frameworks for resilience.

In the framing of any system model, the distinction between system properties and system states is ultimately subjective and defined by the modeller. However, once the variables to be included within the model are defined, their ranges constitute the possible state space of the system. The system state is an instance of the state space. System properties of interest are calculated as a function of the state of the system as shown inFigure 3.1. The values of system properties can change as the state of the system changes, though not necessarily in a linear or monotonic way. What this means is that the value of a system property could recover to a pre-disturbance level though the underlying state of the system has changed and has not returned to the pre-disturbance state.

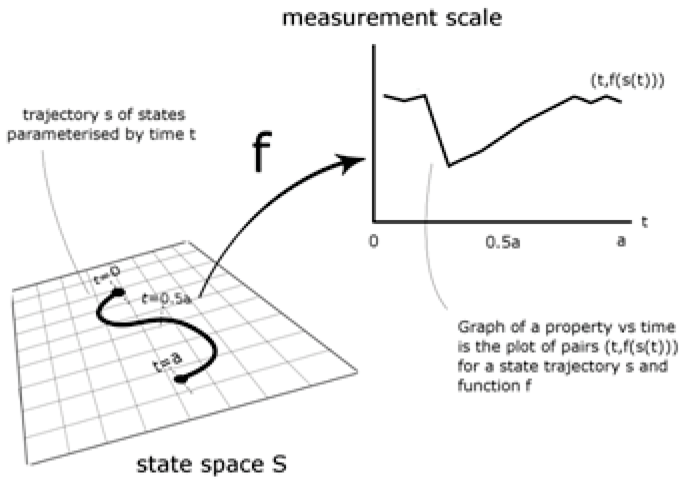


Figure 3.1. Schematic of a system property being calculated as a function of state as state changes with time(Bean et al., 2009).

Note that there is no pretense in the modeling of a system that the state space is a) exhaustive, b) contains the majority of pertinent factors upon which the properties of interest depend, c) that all non-pertinent features have been removed. Ideally, the state space provides the fundamental inputs to model the behaviour of the system as well as the properties of interest.

Figure 3.1 is a depiction of the measurement of a system property as a function f: S⟶R. Here, R is the field of real numbers; for each state s in the state space S, the value of the system property can be assigned any value in R by the function f. In mathematical language, the inputs to the system property f form its domain as a function (so the domain is the state space S), and the output values f (s) ∈ R represent the measurement or metric value of the system property f when the system is in the state s ∈ S. The range of the function f represents all possible measurement or metric values of the property.

The representation of a system property as a function on system states makes the implicit assumption that measurement of system properties does not change system states. This is certainly not the case in all social ecological systems, where interventions aimed at measuring resilience or vulnerability are themselves interventions which change the behaviour of the system.

It is also worth reviewing the classical mathematical definitions of stability.When a system is perturbed, there are three possible kinds of behaviour:

1. The state of the system can return to its original state. This behaviour is classified as asymptotically stable.
2. The state of the system can remain in a neighbourhood of the original state. This behaviour is classified as stable.

3. The state of the system can move away and not come back. This behaviour is classified as unstable.

   Note that this highlights that definitions and measures of resilience that focus on returning to the same equilibrium or a neighbourhood of the same equilibrium are, in fact, referring to stability. For the term resilience to mean more than stability, the third dimension of adapting and benefiting is needed.

3.3. Measures of Robustness/Resistance

Some researchers and practitioners are interested in how much disturbance a system can withstand while maintaining the values of certain state variables or system properties. Examples are water engineers who are interested in a specific supply of water irrespective of changes to the storage or distribution system(Yazdani et al., 2011),transport engineers who are interested in making sure the flow of traffic through a network is maintained even if various nodes or links in the network are destroyed(Berche et al., 2009), internet service providers who are equally concerned with maintaining throughput of traffic irrespective of disturbance (Doyle et al., 2005)and the aviation industry which is concerned that planes stay in the air irrespective of the numerous disturbances that can affect them (Dekker et al., 2008). This type of behaviour is relevant for providers of services, utilities and those concerned with safety and security, including those involved with national safety and security(Burke et al., 2007). Dekker et al. proposed the following working definition of resilience: 'A resilient system is able to adjust its functioning prior to, during or following changes and disturbances, so that it can continue to perform as required in the case of a disruption or major mishap, and in the presence of continuous stresses'(Dekker et al., 2008). Bruneau et al. even call this type of behaviour robustness, which is consistent with the framework used in this chapter: 'Robustness referring to engineering systems is, "the ability of elements, systems or other units of analysis to withstand a given level of stress, or demand without suffering degradation or loss of function"'(Bruneau et al., 2003). Often the key property of interest is performance or function.

In order to measure the amount of disturbance a system can withstand before the values of key variables or properties change, the response of the system to disturbance can be simulated mathematically, or empirical measurements can be collected from disturbances that have happened in the real world and estimates made based on these. Thus, two types of measures of robustness can be found in the literature: various kinds of mathematical models that estimate the amount of disturbance a system can take before the values of specified state variables or system properties changes, or empirical field measurements of how much disturbance the system withstood before the same happened.

Any type of mathematical representation can be used to build a model of the system that can be used to calculate the impact of specific disturbances on the key variables/properties that need to be maintained. By subjecting the model to specific disturbances and undertaking sensitivity analyses, researchers can calculate the magnitudes of specific types of disturbances that cause a change in key performance variables. Berche et al. built graph representations of transport systems and subjected them to different scenarios of attacks on hub nodes and key links (Berche et al., 2009). They used graph and network theoretic approaches to determine how many hubs or links could be removed while maintaining system performance in terms of throughput through the network, and proposed graph theoretic measures of resilience. Drury and Lodge used differential equations to build a dynamical system model of marine ecosystems and subjected them to various harvesting and management strategies (Drury and Lodge, 2009). Wolter et al. built continuous time and discrete time markov models of computer systems and subjected them to shocks(Wolter et al., 2012). Kok built Fuzzy Cognitive Maps of the Amazon and examined the behaviour of the system under different combinations of policies and stressors (Kok, 2009).

3.4. Measures of Stability/Recovery

The majority of the quantitative frameworks for resilience are concerned with recovery of some kind of pre-disturbance conditions, whether the original system state or the values of key system properties or functions. Accordingly, quantitative frameworks involve approaches to measurement of return times or rates, return paths, and the maximum amount of disturbance a system can absorb before recovery to pre-disturbance values is not possible. This section covers return times and rates; return paths, hysteresis and tipping points; stability landscapes, basins of attraction and their associated measures.

3.4.1. Resilience and Return Time

The time taken for the values of specified variables or properties to return to pre-disturbance values is often used as a measure of resilience(Majer, 1990, Adger, 2000, Pimm and Lawton, 1977, DeAngelis, 1980, Maguire and Hagan, 2007, Cimellaro et al., 2010, Neubert and Caswell, 1997, Matsinos and Troumbis, 2002, Pimm, 1991, Holling, 1973, Ortiz and Wolff, 2002). Cimellaro introduced return time in engineering in order to quantify resilience as the normalized area underneath a function Q(t) that represents the functionality of a system, between the time of displacement and time of recovery to pre-disturbance values of Q(t) (Cimellaro et al., 2010).

In dynamical systems, some authors use have used asymptotic rate of convergence as a measure of resilience; the larger the rate of convergence the more resilient the system is thought to be, since it returns more quickly towards pre-disturbance conditions (Martin et al., 2011). Murray et al. show that the asymptotic rate of convergence equals the inverse of the dominant eigenvalue of the linearization of the system of equations(Murray et al., 1994).However, many authors use the dominant eigenvalue as an estimate of the asymptotic rate of convergence, which they use as a measure of resilience (Pimm and Lawton, 1977, DeAngelis, 1980). As these indices refer to asymptotic stability, Neubert and Caswell proposed indices for broader stable behaviour(Neubert and Caswell, 1997).

In the case of agent-based models or cellular automata, the behaviour of the system in response to disturbance is simulated and resilience is calculated as the inverse of the time needed for the system to return to its original state after disturbance(Ortiz and Wolff, 2002) or to reach a certain percentage of a specified property, such as abundance (Matsinos and Troumbis, 2002).

3.4.2. Property Versus Time Graphs

A great many quantitative frameworks for resilience focus on the graph of specific system properties of interest, over a time interval where some stress or shock occurs, and ascribing aspects of resilience to features of the graph (Majer, 1990, Adger, 2000, Cimellaro et al., 2010, Tamvakis and Xenidis, 2013). Figure 3.2 is provided as a representative example. It is a reproduction of Majer's model of ecological resilience (Majer, 1990), which attempts to quantify resilience in terms of changes in system properties over time.

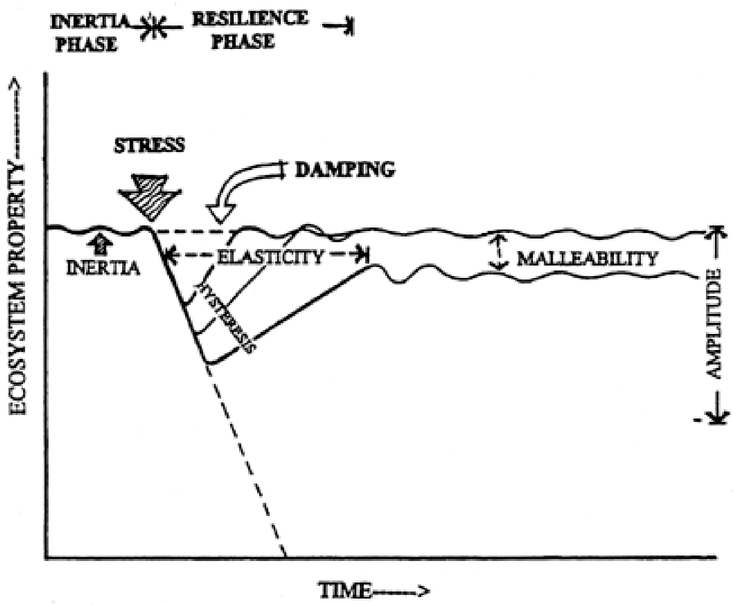


Figure 3.2. Property Versus Time Graphs Used to Quantify Resilience (Majer, 1990).

From Westman (Westman, 1978), who follows Orians (Orians, 1975), defines amplitudeas the extent to which a system can be stressed before it loses its ability to recover, elasticityis defined as the time taken by the system to recover, hysteresis is the degree of similarity of the trajectory of recovery to the trajectory of decline; and malleability is defined as the ease by which the system can be become permanently altered by stresses. Figure 3.2 is illustrative of a common practice of ascribing aspects or components of resilience to features of the graph. Each of the terms are meant to refer to thresholds, attributes and capacities of the system itself. However, Figure 3.2 depicts the amplitude, elasticity, hysteresis and malleability, respectively, of the values of a particular ecosystem property.

To what degree do the values of an ecosystem property reflect the ecosystem? The hysteresis of an ecosystem, as described by its state, is clearly different from the hysteresis of an ecosystem property. Two different trajectories of the system state to two different end points may evidently have a similar level of recovery of an ecosystem property, as shown in Figure 3.3. Consider the ecosystem property as the population of a particular bird species. The stress is a bushfire. In the first scenario, the previously dominant vegetation supporting the bird species is destroyed by the bushfire. The bird species slowly adapts to the replacement vegetation as a food source and populations levels increase. In the second scenario, the original vegetation is destroyed but regrows with competition, slowly regaining its dominance. The bird species stays with the food source it knows and the population levels of the bird species increase as the amount of original vegetation increases. In both scenarios, assume that the population increase is at the same rate. Then the trajectories of recovery of an ecosystem property (population) are identical, even though the trajectories of the system's state are radically different. One scenario involved 'recovery' of the original state of vegetation, the second involved adaptation by the species to an alternate state of vegetation.

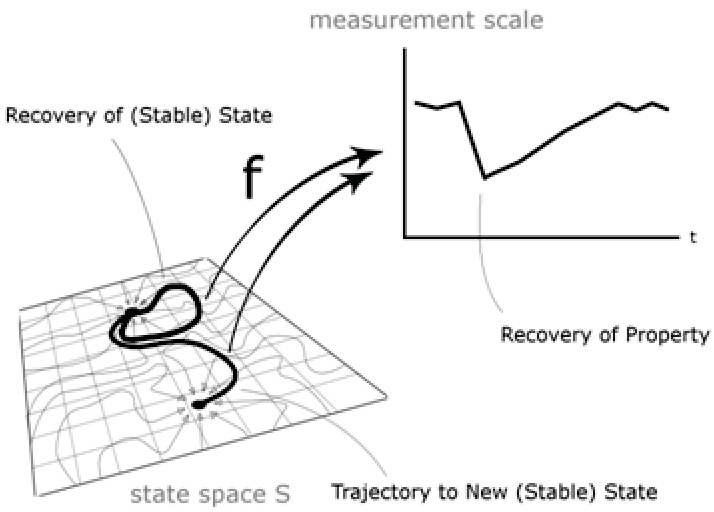


Figure 3.3. Multiple different state trajectories may produce the same recovery rates of a given system property (Bean et al., 2009).

While it is evident that recovery of an ecosystem property to an original level and recovery of an ecosystem to its original state are not the same things, the literature on quantitative frameworks for resilience omits reinforcing the distinction. Omitting this distinction does cause confusion, since it is not clear what the author describing resilience with a graph like Figure 3.2 means when they talk, for example, about hysteresis. Are we talking about the trajectory of some system property or the system state when we say a system exhibits hysteresis? The graph depicts the trajectory of a system property; however, prominent resilience authors, such as Sheffer and Adger, clearly infer hysteresis is the similarity between trajectories of system state(Adger, 2000, Scheffer et al., 2001). What should we understand by the term, hysteresis, then?

As an example of how this could be confusing, consider the component of resilience termed 'creativity' in Figure 3.4 (Adger, 2000). Creativity is identified graphically as when a community's 'level of function' (here reduced to a single measurable parameter) exceeds the pre-stress or pre-shock level. This may simply be meant metaphorically as 'ending up better off'; however, as a quantitative framework for resilience, it is problematic.

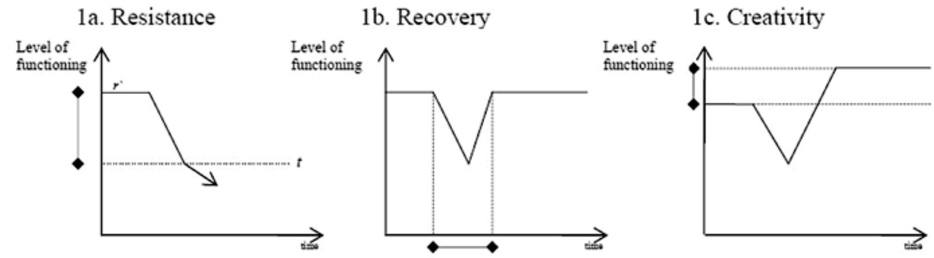


Figure 3.4. Components of social resilience: resistance, recovery, creativity(Adger, 2000).

Few would argue that creativity is part of the way a community responds to stress or shock and that creative responses may, or may not, result in exceeding pre-stress levels of functioning upon recovery. In quantitative terms, the way a community responds is indicated by trajectories of state and different end points. Differences in trajectories of state may, or may not, reflect in differences in the values of a single system property. If 'function' was measured in terms of number of hours spent in paid employment per capita, perhaps a community would decide to reduce this and redefine their way of being following disturbance that highlighted for them the importance of time spent with loved ones.

The depiction of resistance in Figure 3.4 is also problematic. It provides the impression that the 'higher' the values of a system property are above a threshold t, the more resistant the system is to collapse (indicated by values of the property below the threshold t). This is like assuming the higher the stock index the safer the market is from fiscal collapse. Implicit in Figure 3.4 are assumptions of linear relationships between stresses and level of functioning, which cannot be assumed apriori. Figure 3.5 can be viewed as a depiction of potential non-linear relationships between stresses or shocks and values of a system property.

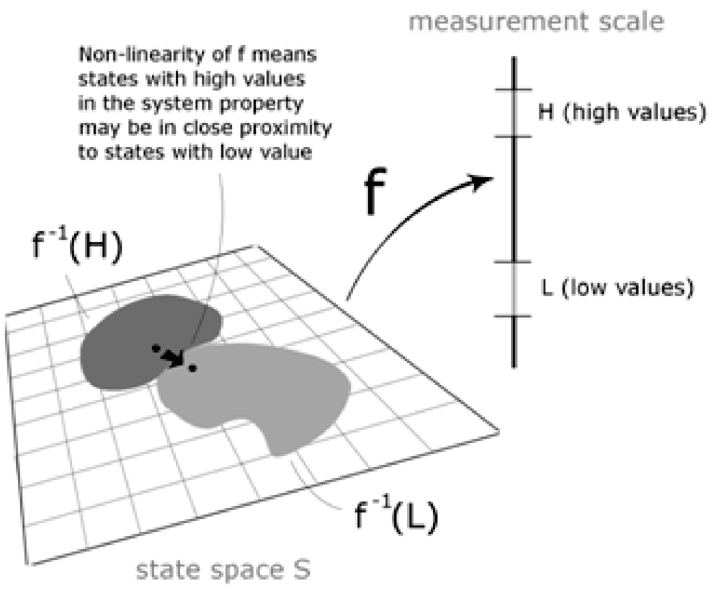


Figure 3.5. State space areas corresponding to high and low system property values.

To ignore the consideration of the system's state space is to be quantitatively ignorant of how the system property recovered. Resistance/recovery of state and resistance/recovery of property are clearly distinguished when a system property is explicitly treated as a function on system states. Further, potential non-linearity in the relationship between stresses and system properties can be identified. That is, small changes in state may result in large changes in a system property, debunking the idea that, per se, high levels of a system property are a buffer against stresses and shocks, as shown in Figure 3.5.

3.4.3. Stability Landscapes, Regime Shifts and Resilience

The most pervasive quantitative description of resilience, popularized by the Resilience Alliance, is an extension of the ball-in-cup metaphor. It uses dynamical systems to describe resilience in terms of three quantifiable aspects of a basin of attraction(Walker et al., 2004), each of which is represented in Figure 3.1:

1. Latitude: the breadth of a basin of attraction.
2. Resistance: the depth of a basin of attraction.
3. Precariousness: the distance of the current state of the system from the edge of a basin of attraction.

Together, these three aspects are meant to provide a measure of the amount of disturbance a system can handle without being pushed into an alternate basin. Maintenance of the same basin is interpreted as resilience. Each basin is thought of as a regime and changing basin is interpreted as 'regime shift'. It is assumed that some basins are good and others are bad. Walker et al. refer to the surface representing the solution space asa system of differential equations used to describe the system of interest as a 'stability landscape'(Walker et al., 2004).

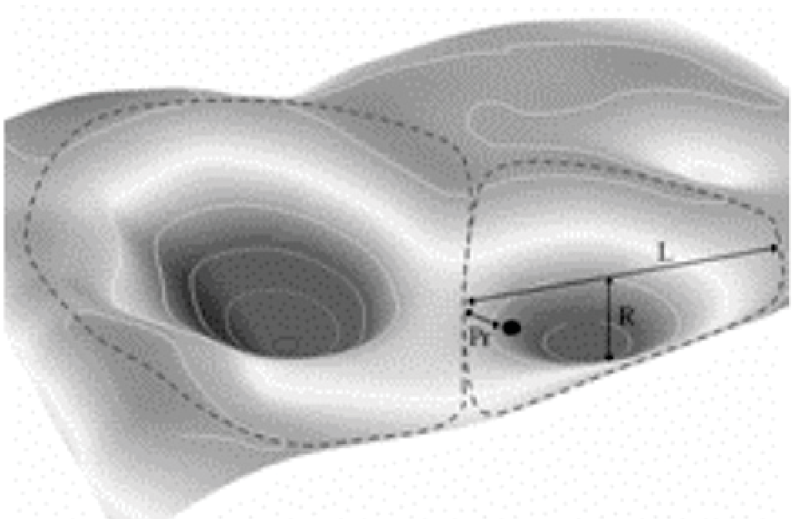


Figure 3.6. Three-dimensional stability landscape with two basins of attraction. The current state of the system is in one of the basins. The three factors defined to quantify resilience are shown as L - latitude, R = resistance, Pr = precariousness.

Many other authors have taken up the quantitative framework for resilience in terms of the distance between the state of the system and the boundary of the 'good' attractor (Collings and Wollkind, 1990, van Coller, 1997, Anderies et al., 2002). However, there are various issues with this representation. Note that these measures of resilience apply to an entire basin and do not differentiate between different states within the basin, even though you would imagine different resilience values for states nearer the boundary versus nearer the equilibrium or for states that are more or less desirable within the basin. These measures are quite crude.

Furthermore, latitude and resistance are both ill-defined concepts. What is the depth of the basin shown in Figure 3.7.

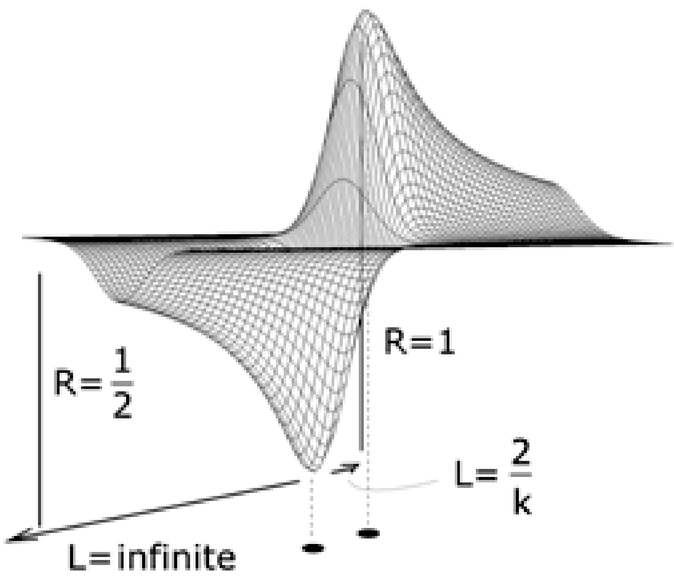


Figure 3.7. Graph of f(x,y) = kx(1+(kx)2)-1 exp(-y2) for positive k, an example of a basin with different depth and latitude in different directions.

In one direction,a trajectory on the surface would have to achieve a vertical displacement of 1/2 to reach the lip of the basin. In the opposite direction, the trajectory would have to achieve a vertical displacement of 1. Considering all trajectories exiting the basin, there is acontinuum of such 'depths' [1/2, 1]. For a well-defined concept of depth, one has to consider the vertical displacement in a certain direction–or define a choice of value from all depths in all directions, for example, choosing the minimum depth of all possible paths out of the basin.

This is not a technicality. Walker et al. might simply have wanted R to depict how hard it is to get out of the basin, but this misrepresents that there is no single and simple answer about how hard it is to leave a domain of attraction(Walker et al., 2004). The diagrams used by Walker et al. and Gunderson et al. shows basins that are uniform in all directions. However, it would be manifestly false to believe that all landscapes representing systems of concern to scientists or managers would have basins of equal depth in all directions(Walker et al., 2004).

Recognizing that landscapes generally will have basins of unequal depth means recognizing that systems have different 'resistance' in different directions. The choice of the minimum depth is a worst-case scenario estimation. In the terminology of Walker et al., this choice says that the system, when the system state is in that basin, is only as 'resistant' as its minimal resistance in any direction. Examine this notion for the Rosenbrock function (Rosenbrock, 1960).

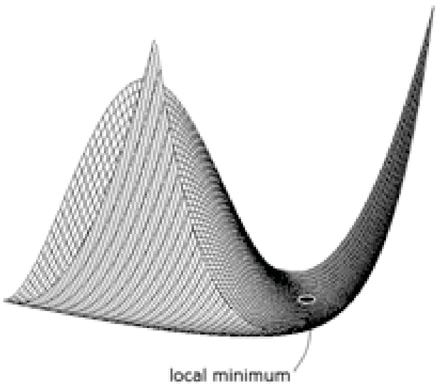


Figure 3.8. Graph of Rosenbrock Function has local minimum set in a shallow valley with steep walls.

Choosing to define a system's resistance by the minimal slope along the shallow valley completely ignores the steepness on either side. Unless random stresses and shocks in directions along the valley completely dominate the likelihood of those fluctuations perpendicular to the valley, the minimal slope amounts to a conservative estimate of the 'resistance' of the system to state change.

The traditional concept of how hard it is to get out of a basin caused by a potential is work. Partially R is trying to depict work, and work is a feature of trajectories. If you ask, 'How much work has to be done to leave the basin? 'the immediate rhetorical response is 'in which direction?' Even with substituting depth by work, resistance should not be associated with depth without qualification.

Similar comments apply to latitude. The component L, represented in Figure 3.6, is ill-defined. Considering the surface in Figure 3.7, latitude is infinite in one direction and 2/k in the other. Indeed, latitude can be made arbitrarily small in one direction and remain infinite in the other. Again, one can either choose a value from [2/k, ∞) to be the latitude of such a basin or recognize that latitude, too, is a feature of trajectories of state. If you ask, 'How much latitude does my system have to stresses and shocks?' you must again rhetorically answer 'in which direction?'

The only certain thing that R and L in Figure 6depict – corrected to take into account direction – is recovery of equilibrium state. It is certain that, if R is high and L is small, the average rate of recovery in that direction will be greater than if R is low and L is large. It is also certain that, if L is large, there is a greater chance of recovering back to an equilibrium state after stochastic fluctuations in that direction than if L is small.

Beisneret al. surveyed two perspectives on how ecosystems transit from one equilibrium state to another(Beisner et al., 2003). One was the idea that a forced trajectory of state or a sufficiently severe stochastic perturbation of state may shift the system state from the domain of attraction of one equilibrium state to another. Beisner et al. termed these changes in state for a fixed dynamical action 'shifts in variables'. The other idea is that the dynamical action itself might change and that the current system state will follow a new flow line to an alternate equilibrium state. Beisner et al. termed such changes in dynamics 'changes in parameters'.

Beisner observed that, if both the state and the dynamics of a system can change, then one can define an enlarged 'state' of the system at any particular instant to be the current state and the current dynamics (Beisner et al., 2003). Mathematically, let S denote a state space and Q a parameterised set of dynamical actions on S, for each fixed $q \in Q$, the pair (S,q) is a dynamical system. The cartesian product $S \times Q$ represents the enlarged 'state' space of the system. Graphical features, such as R and L, depict capacities of the system in purely constant q directions. No graphical feature, or any other type of feature, on landscapes over S for a fixed dynamical action q can represent resistance to changes in such dynamics. The absence of components of resilience in non-constant q directions means such an approach is incapable of representing resilience to changes in dynamics, only to changes in state.

While the qualitative descriptions of resilience given by Walker et al. and the Resilience Alliance describe it as a multi-scale, multi-basin concept, these quantitative definitions are neither multi-scale nor multi-basin; they relate only to a single basin at a single scale. We note also that the desirable values of the properties of interest might not correspond to the boundary of a single basin; so, in practice, it will be important to decouple the quantitative measurement of resilience from single basins of attraction. There is no reason why leaving the basin in this direction constitutes a risk, especially if, on the other side, is an equally/more desirable basin.

Resilience 'to what' is also important. Supposing an undesirable basin lies in the direction of minimum distance, such a position may not be as risky as it seems if stochastic fluctuations are not uniform and there is more chance of being perturbed in a certain direction (correlated fluctations). This can lead to one state that is deemed less precarious than another actually being more precarious (see Figure 3.9). In general, going back to system properties decoupled from dynamical actions, the minimum distance from an initial state to the nearest domain of attraction underneath 'low ground' is not necessarily a good measure of precariousness because it does not take into account the nature of the disturbance.

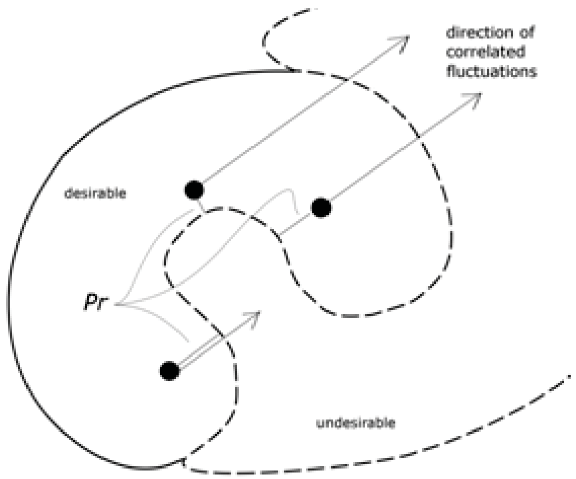


Figure 3.9. Precariousness Pr, the shortest distance to the edge of the basin, does not take into account the nature of the disturbance.

In summary, resilience needs to be decoupled from the geometry of single basins of attraction. Since we may want to measure resilience irrespective of the type of mathematical model being used, it would be useful to decouple from basins altogether. What we clearly need to define in order to quantify resilience are the boundaries of the system of interest, the relevant state variables and their ranges, the dynamics of the system, the relevant system properties as a function on the state space, the nature of the disturbances involved and to some metric of desirability over the state space and/or relevant system properties.

3.4.4. Thresholds, Tipping Points and Regime Shifts

As described in Chapter 2 Section 2.3.2.of this thesis, the terms,'threshold' and 'tipping point', are often used interchangeably in the resilience literature to refer to the point values of key variables, which, if crossed, cause a system to shift from one 'regime' to another (Scheffer et al., 2001, Hughes et al., 2007).Resilience is often formulated as the magnitude of disturbance a system can absorb before crossing a threshold and flipping into an alternate regime (Holling and Gunderson, 2002, Resilience Alliance, 2002, Hughes et al., 2007, Walker et al., 2004). These definitions of ecological resilience echo the conceptualization of resilience as absorbing and recovering from disturbance. The focus of these definitions is on maintaining essentially the same qualitative condition or regime, involving the same identity, structure, functions and feedbacks.

Within the resilience literature, regime shifts are sometimes visualized in terms of jumps or discontinuities in particular variables, in which case the value of the variable at the discontinuity is thought of as the threshold. Different regimes are also visualized as different basins of attraction, in which case the edge of the basin is thought of as the threshold or tipping point. These two visualizations are not equivalent. There need not even be a discontinuity in the dependent variables during the transition from one basin to another if the landscape is smooth(Helfgott, 2006).Stability landscapes and basins were discussed in Section 1.4.3.

Significant work has been done to model and quantify the values of thresholds or tipping points for various ecosystems and to determine how far the system is from such thresholds in order to inform management decisions. Often attempts to quantify tipping points correspond to researchers seeking to quantify the distance to the edge of a basin in a dynamical systems model of the social-ecological system, as shown in Figure 3.6;or using bifurcation theory to examine critical fixed points and fold bifurcations, as shown in Figure 3.10; andby determining the values of key variables when qualitative shifts occurred empirically.

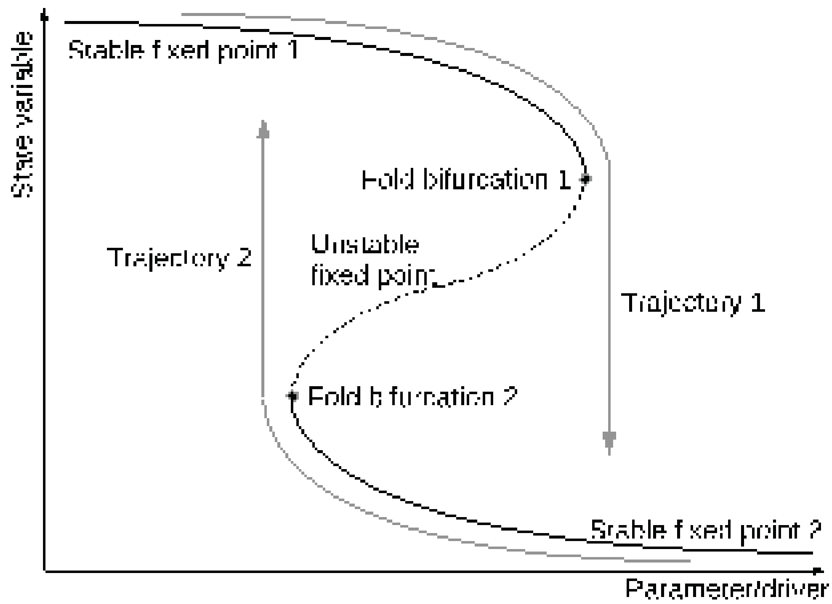


Figure 3.10. Fold bifurcations and regime shifts(Lade et al., 2013).

The Stockholm Resilience Centre has an ongoing program collecting and developing a Regime Shifts Database to provide a high-quality synthesis of different types of regime shifts that have been documented in social-ecological systems, including coral reefs, freshwater lakes, marine systems and savanna rangelands (Stockholm Resilience Centre, 2014). They use empirical data to identify the values of tipping points as well as dynamical systems models, where they examine the boundaries of basins of attraction. Laurence et al. have classified how close ten Australian terrestrial ecosystems believed to be 'most vulnerable to tipping points' are to those tipping points(Laurance et al., 2011). They used a Delphi technique to survey experts and rank how vulnerable each Australian ecosystem was on a scale of 0-3. The ecosystems covered include elevationally restricted mountain ecosystems, tropical savannas, coastal floodplains and wetlands, coral reefs, drier rainforests, wetlands and floodplains in the Murray-Darling Basin, the Mediterranean ecosystems of southwestern Australia, offshore islands, temperate eucalypt forests, salt marshes and mangroves. There are a great number of other studies identifying the location of, and distance to, tipping points in ecological, social-ecological and biophysical systems, including extinction of populations in deteriorating environments (Drake and Griffen, 2010), ocean thermohaline circulation (van Nes and Scheffer, 2007), climate system tipping points (Held and Kleinen, 2004, Lenton et al., 2009, Kriegler et al., 2009), societal mobilization for action on critical issues (Scheffer et al., 2003), common pool resource harvesting (Lade et al., 2013),and many more.

One of the most well-known instances of numerical values assigned to tipping points is Rockström et al.'s Planetary Boundaries paper(Rockström et al., 2009a), summarized in a Nature Feature as 'Asafe operating space for humanity' (Rockström et al., 2009b). The paper identifies nine key planetary systems and measurable proxies for their status. It assigns numerical values to each of these proxies that represent boundaries that cannot be crossed or the Earth system will tip into unstable behaviour that may not be able to support human civilization. 'These boundaries define the safe operating space for humanity with respect to the Earth system and are associated with the planet's bio-physical subsystems or processes. … If these thresholds are crossed, then important subsystems, such as a monsoon system, could shift into a new state, often with deleterious or potentially even disastrous consequences for humans. …Determining a safe distance involves normative judgments of how societies choose to deal with risk and uncertainty. We have taken a conservative, risk-averse approach to quantifying our planetary boundaries, taking into account the large uncertainties that surround the true position of many thresholds'(Rockström et al., 2009b).

The nine key planetary processes identified are: climate change; rate of biodiversity loss (terrestrial and marine); interference with nitrogen and phosphorus cycles; stratospheric ozone depletion; ocean acidification; global fresh-water use; change in land use; chemical pollution; and atmospheric aerosol loading, as shown in Figure 3.11 and Table 1(Rockström et al., 2009b). In Figure 3.11, the green represents the safe space within the assigned thresholds and the red represents the current estimate of the status of each variable. The boundaries of biodiversity loss, climate change and human interference with the nitrogen cycle have already been crossed. Table 1gives the numerical values of each threshold, the estimate of the current state, and the estimate of the state pre-industrialization.

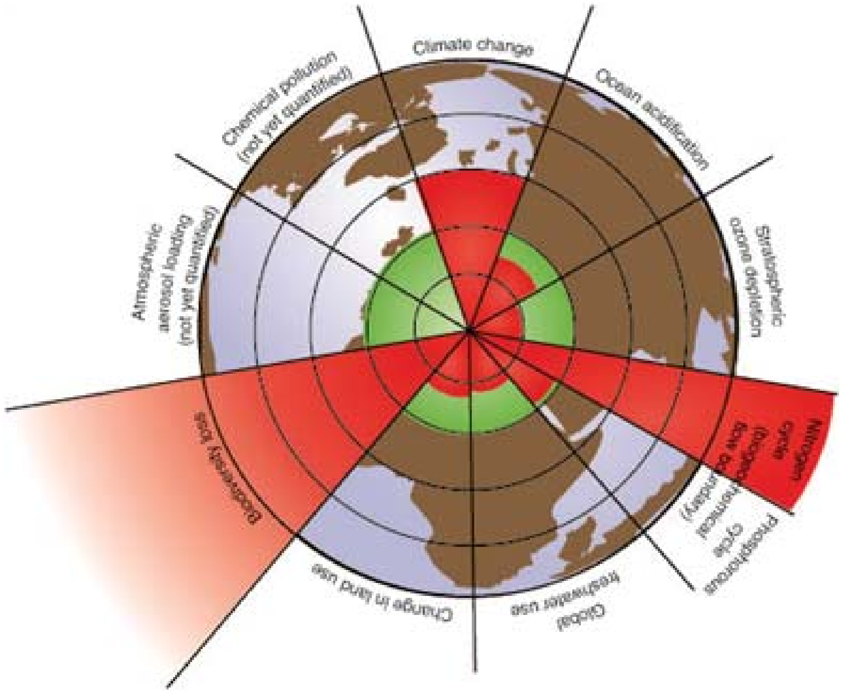


Figure 3.11. Planetary Boundaries. Image credit: Stockholm Environment Institute (Rockström et al., 2009b).

While the paper is explains clearly that these key variables are highly interrelated, the thresholds are given as static numerical values rather than as a function of other variables. You would expect, for example, that the threshold for biodiversity loss is less in combination with climate change and land-use change. The calculations examining the tipping point of each variable are often done in isolation for fixed values of the other variables. This representation does not take into account multiple interacting stressors, interconnectedness and non-linearity.

Table 3.1. Planetary boundaries: numerical thresholds for 10 Earth-system processes (Rockström et al., 2009b). Data sources: (Rockström et al., 2009a).

PLANETARY BOUNDARIES				
Earth-system process	Parameters	Proposed boundary	Current status	Pre-industrial value
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	280
	(ii) Change in radiative forcing (watts per metre squared)	1	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per million species per year)	10	>100	0.1–1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Amount of N_2 removed from the atmosphere for human use (millions of tonnes per year)	35	121	0
Phosphorus cycle (part of a boundary with the nitrogen cycle)	Quantity of P flowing into the oceans (millions of tonnes per year)	11	8.5–9.5	~1
Stratospheric ozone depletion	Concentration of ozone (Dobson unit)	276	283	290
Ocean acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.90	3.44
Global freshwater use	Consumption of freshwater by humans (km^3 per year)	4,000	2,600	415
Change in land use	Percentage of global land cover converted to cropland	15	11.7	Low
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis		To be determined	
Chemical pollution	For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in, the global environment, or the effects on ecosystem and functioning of Earth system thereof		To be determined	

Acknowledging that it is difficult to calculate the numerical value of tipping points, there is quite a lot of literature on empirically detecting when we might be close to a tipping point, or 'Early Warning Systems'(Brock and Carpenter, 2006, Scheffer, 2010). This makes sense for those involved in preserving the Amazon or the Great Barrier Reef for example. Development of an early warning system for Amazon dieback in connection with land use and climate change is the topic of a large EU FP7 Research Program known as AmazAlert, which the author of this thesis has been involved in.

A number of signals have been identified, which could indicate that a system is close to a tipping point. Scheffer says there will be an increase in the 'frequency spectrum and variance of the state of the system' close to the tipping point, and also that there will be an increase in autocorrelation – 'subsequent states in a time series will become more alike' as the system state approaches a tipping point (Scheffer, 2010). These phenomena have been found in models of the collapse of thermohaline circulation (Held and Kleinen, 2004, Lenton et al., 2009) and in climate system tipping points. Dakos et al. show that 'a systematic rise in autocorrelation has been found in eight major climate transitions in the past'(Dakos et al., 2008). Brock, Carpenter and Biggs have performed extensive work on variance as a leading indicator of tipping points in ecosystems (Brock and Carpenter, 2006, Biggs et al., 2009). It has been suggested that we can measure recovery rate following disturbance as an indicator for how close we are to a tipping point (van Nes and Scheffer, 2007, Dai et al., 2012) as 'systems that are close to a tipping points are very slow in recovering from perturbations, a phenomenon known as "critical slowing down"'(Scheffer, 2010). A heuristic illustration of critical slowing down is given in Figure 3.12, showing characteristic changes in non-equilibrium dynamics as a system approaches a tipping point.

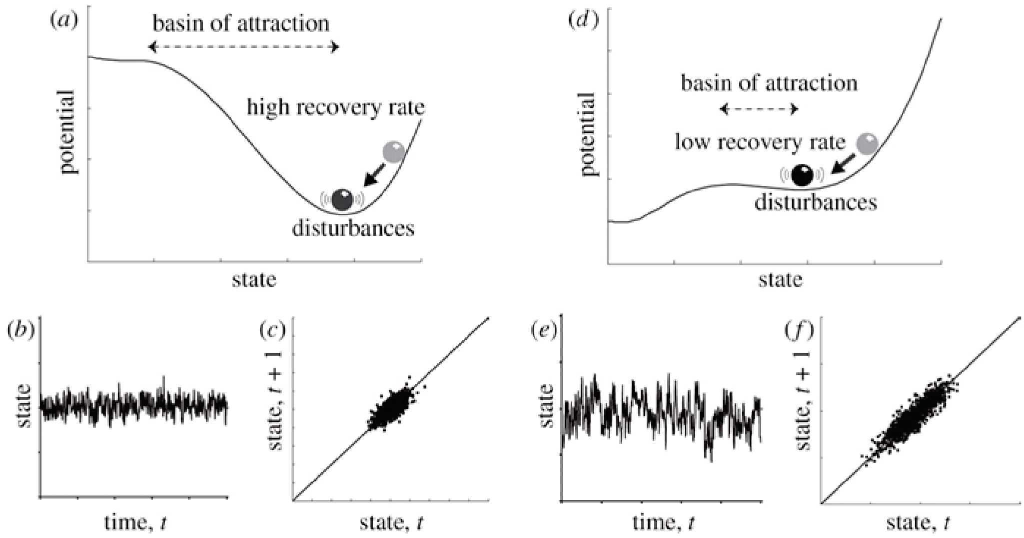


Figure 3.12. Heuristic illustration of critical slowing down.

According to Scheffer, these' symptoms detected belong to a family of generic leading indicators that may help to determine whether a complex system is on the brink of collapse'(Scheffer, 2010).Questions remain about how to deal with the normative content in the framing of such models: what makes a system what it is and what constitutes system collapse (that we are trying to detect) is not always simple to define. A lot of the work on detecting tipping points seems to assume that 'systems' have concrete existence independent of the inquirer/modeler and therefore that their 'collapse' would always be accompanied by such indicators. However, this seems a very questionable assumption.

The author has come to suspect that scientists and politicians love tipping points for precisely the opposite reasons. Broadly speaking, scientists involved in the calculation or detection of tipping points are interested in protecting systems such as the Amazon or the Great Barrier Reef from collapse. Politicians seem to be interested in these thresholds because it gives them one, simple, static number that says exploitation of the environment can continue up to that point. For example, if it is calculated that we can clear 60% of the Amazon without the Amazon flipping to savannah, then this gives those who are balancing human development and environmental conservation objectives a license to clear up to 60% of the Amazon.

The danger here is that the models are quite possibly wrong. Furthermore, static numerical values for single variables do not adequately take into account interactions between variables and multiple stressors, let alone the stressors left out of the model, and the real thresholds could be much less than we anticipate. Another danger is that, if these models allow us to believe we can predict tipping points where they exist, there is the risk of being blinded to other weak signals of future change (Ramírez and Ravetz, 2011).

3.5. Measures of Adaptability

The resilience literature surveyed throughout this thesis does not reveal any formal mathematical models of adaptive capacity in terms of Ryan's mechanisms 'generating variety, observing feedback from interactions with the environment, and selection to reinforce some interactions and inhibit others'(Ryan, 2007). There are indicator-based approaches that use proxies (such as those found in Jones et al.'s framework for adaptive capacity (Jones et al., 2010) covered in the previous chapter) to estimate the capacity of a system do these three things.

Most of the indicator-based measures of resilience arise from the social resilience literature, in particular community resilience and disaster resilience. As described in the previous chapter, most studies of community and disaster resilience have sought to empirically identify the factors that underpin the ability of a community or society to absorb disturbance, or to recover or adapt following disturbance. Most attempts to quantify this are based on measuring proxies for factors thought to underpin system resilience.

For example, Norris et al. provide a model of adaptive capacities required for community resilience, shown in Figure 3.12 (Norris et al., 2008). Sherrieb et al. found measurable indicators for each of the items in the Economic Development and Social Capital sections of this model and subsequently created a composite index for community resilience based entirely on publicly available population data in the United States (Sherrieb et al., 2010).

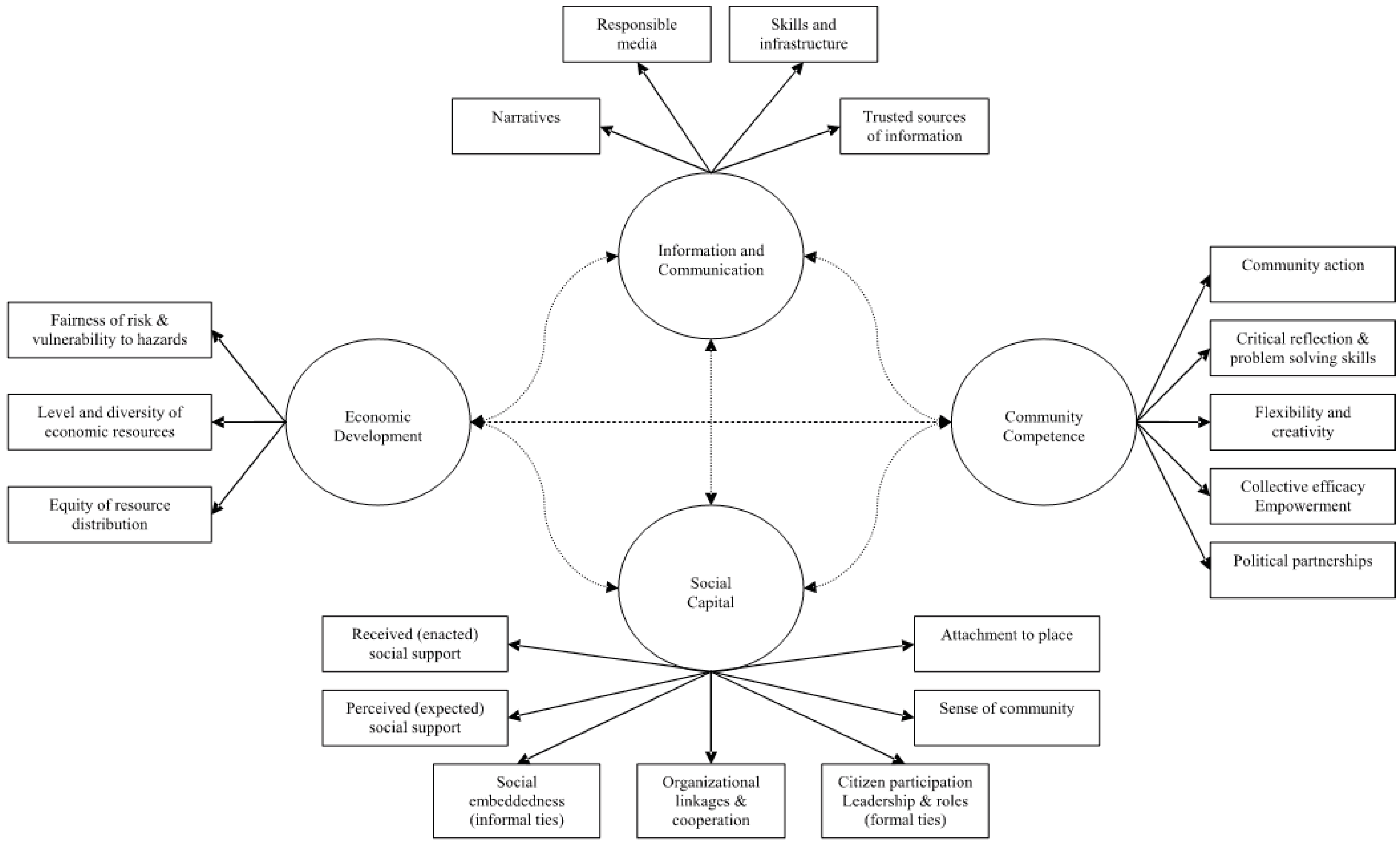


Figure 3.13. "Networked adaptive capacities" that underpin community resilience (Norris et al., 2008).

The process Sherrieb et al. followed is common to the development of such indexes. They created an exhaustive 'wish list' of measures for the items in the Economic Development and Social Capital sections of the framework above. Then they identified data sources that matched their indicators. In their case, they restricted themselves to publicly available archival data; other authors sometimes use other data sources or take their own measurements. Next they tested the correlations between indicators and used principal component analysis to select the most parsimonious group of indicators. Then they combined the remaining indicators into a composite index.

The construction of indexes is relatively simple and has the following steps:

- Choose a set of n measurable variables $x_1, x_2, x_3, \ldots, x_n$.
- Choose a set of weights to apply to each variable $w_1, w_2, w_3, \ldots, w_n$ such that the w sum to 1.
- Multiply each variable by each weight and add together.
- $I = \Sigma w_i x_i$
- If the weights are equal, this becomes an average, a univariate index gives a weight of 1 to one variable and 0 to all other possible variables (e.g. using GDP as an index of well-being is equivalent to giving everything else a weight of 0).
- Sometimes the sum is raised to a power.

Sherrieb et al. identified the following indicators to parsimoniously represent the Economic Development and Social Capital components of the Norris model:

Economic development

Resource level

- Employment/population ratio
- Median household income MDs/10,000
- Corporate tax revenues/1,000
- Percent creative class occupations

Resource equity

- Income equity
- Less than HS education: % African American minus White

Resource diversity

- Net business gain/loss rate
- Occupational diversity
- Urban influence

Social Capital

Social support

- Ratio of 2 parent households w/children to 2 parent plus single parent households w/children

Social participation

- Number of arts/sports organizations/10,000
- Number of civic organizations/10,000
- Voter percent 2004 presidential election
- Religious adherents/1,000

Community bonds

- Net migration rate/1,000 2000 through 2003
- Property crime rate (inverse)

These indicators wereadded together with equal weight within the categories of Economic Development and Social Capital to make an Economic Development and Social Capital Index. Then those two indexes were added together, with equal weight, to obtain the Resilience Index. The calculations were conducted for the state of Mississippi.

Kirmayer et al. elucidate a profound model of the factors that underpin the resilience of Aboriginal communities, called 'Dimensions of Aboriginal Resilience'(Kirmayer et al., 2009). They also develop a list of indicators/measures for each of these dimensions. The dimensions and their associated indicators/measures are shown in Table 2.

Table 2. Aboriginal Dimensions of Resilience.

Resilience Domain	Dimensions	Indicators/Measures
Social Capital		
Bonding	Cognitive	Trust in others from the same group Belief that community is close knit
	Behavioural	Membership in groups within community Number of meetings attended in the last year
	Structural	Strength of ties to groups within community
Bridging	Cognitive	Trust in others from other groups Sense of personal safety
	Behavioural	Membership in organizations based outside community Number of meetings attended in last year
	Structural	Strength of ties to groups outside the community
Linking	Cognitive	Trust in health care professionals Trust in community organizations Trust in different levels of government
	Behavioural	Political activism
	Structural	Number of contacts/meetings with government
Ecological Capital		
	Social Capital	(As above)
	Natural Capital	Quality of environment
	Human Capital	Knowledge, skills, values, diversity
	Built Capital	Infrastructure (housing, water, power, communications)

Resilience Domain	• Dimensions	• Indicators/Measures
Aboriginal Cultural Knowledge, Values and Practices		
	Family and Community Connectedness	Support from relatives Intergenerational communication Positive parenting and family communication Strengths-based interactions in families
	Oral Tradition and Storytelling	Knowledge of traditional stories Community sharing of stories
	Connection to the Land	Participation in land-based activities Consumption of country food Caring for Country (Burgess et al. 2009)
	Healing Traditions	Number of healers or others with healing knowledge Frequency of healing activities Number of people participating
	Spirituality and Ceremony	Number of Elders or others with ceremonial knowledge Frequency of ceremonies Number of people participating
	Collective Knowledge and Identity	Number of different types and frequency of activities to learn, honor or celebrate collective knowledge and identity
	Cultural Continuity	Local control of fire, police, education, social services, and other organizations Cultural heritage centres
	Political Activism	Land claims, self-government, involvement of community in challenges to development

There are around 15 proposed measures of psychological resilience, all of which empirically measure psychometric properties that are seen as underpinning resilience. A systematic review of psychological measures of resilience is provided by Windle et al. (Windle et al., 2011). This review covers all 15 resilience measures and concludes there is no single 'gold standard' approach for measuring individual psychological resilience.

3.6. Conclusions

The measurement of resilience is an extremely challenging task. It requires a deep understanding of the system of interest, the types of disturbances it might be subject to, the way the system could respond to those disturbances and what constitutes desirability of system states or properties.Seeking to measure resilience is seeking to measure something that is highly normative, multi-dimensional, depends on the scope, scale and timeframe of analysis, and varies over time and space and with respect to different social groups.

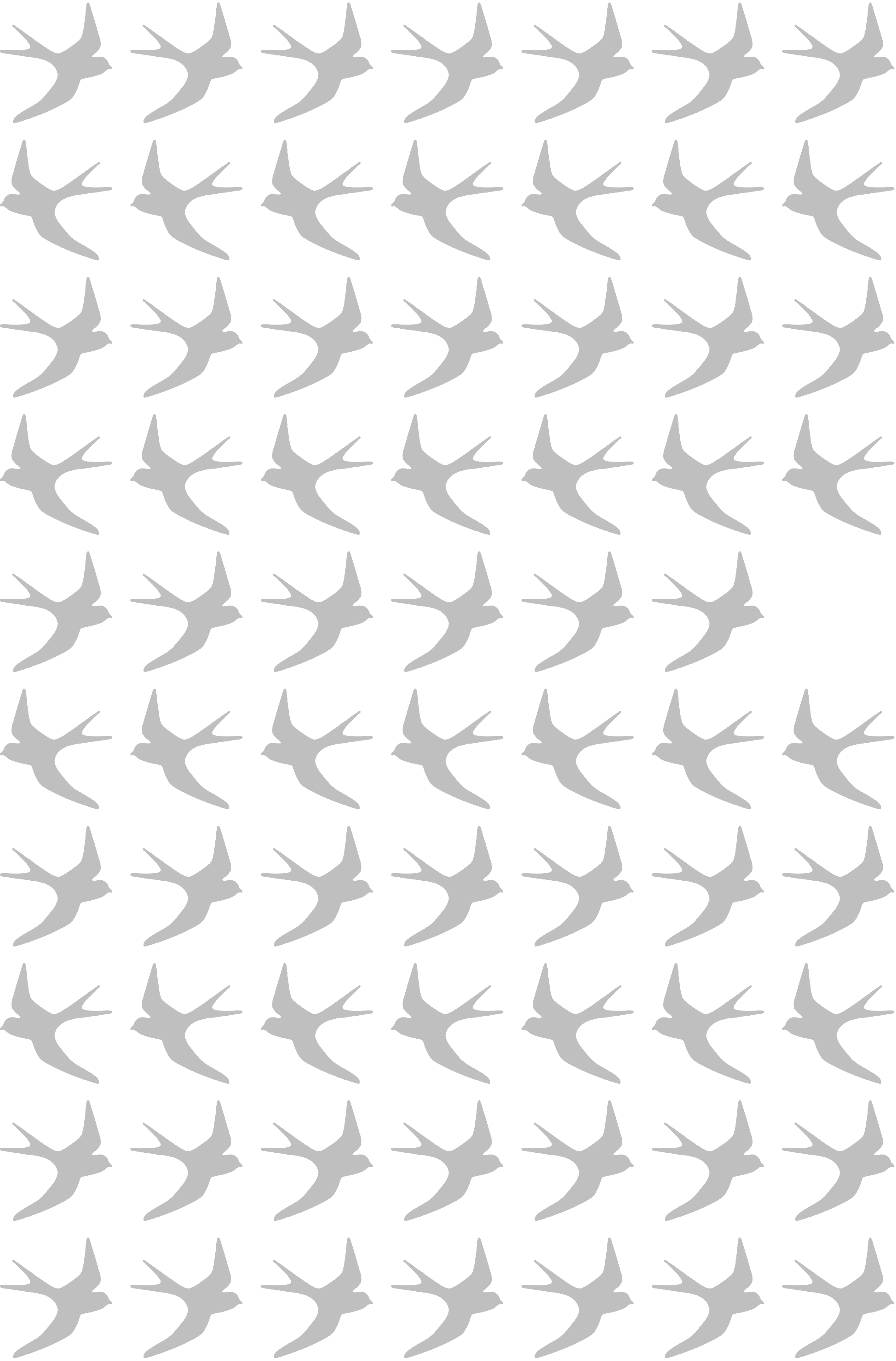
Examination of existing quantitative frameworks for resilience highlights a number of distinctions that are not made in the literature and that open up space for greater freedom and clarity in modeling resilience:

- Distinguish resilience of system states from resilience of system properties, allowing the modeller to capture the way the system resists, recovers from or adapts to disturbance or change and avoiding the confusing issues identified in Section 1.4.3.
- Calculating system properties as functions on the state space aids in the previous point and also makes it possible to:
- Decouple resilience from single states or single basins of attraction, noting that the desirable subset of the state space might not correspond to a single basin. In this way resilience is not limited to only robustness and stability, but could potentially change and benefit as a result of disturbance or change.

If the desirable sets of states are defined in terms of desirable system properties (rather than as artifacts of the dynamical systems model), the desirable sets of states are not necessarily attractors and it is not possible to base definitions of resilience on the size of basins or convergence rates to attractors. In fact, resilience is not a property of a dynamical systems model, a graph theoretic model, a stochastic model, or in fact any type of model. Irrespective of the type of model we have, we want to be able to be resilient. Irrespective of whether we have basins of attraction, discontinuities, hysteresis or sudden tipping points, we want to be able to be resilient.Whether change is sudden and shocking or slow and gradual, we want to be able to be resilient to it. In fact, resilience needs to be decoupled from all of these things. Irrespective of the type of model we have, measures of resilience should surely depend on how much we like where we end up following disturbance relative to the pre-disturbance state. A quantitative framework for resilience that builds on these ideas is applied to food system resilience as an illustrative example in Chapter 7.

Note that whatever type of mathematical framework for resilience we use, we will need to define the variables to be included and the state space of the model (the possible values of the variables in the model). There are two types of uncertainty and unknowability that are often confabulated. The first kind is where it is difficult or impossible to predict the state of the system, or to assign probabilities to each of the states in the state space due to complexity, and potentially other issues such as lack of data and limits of knowledge. The second kind of uncertainty and unknowability relates to the fact that we can't possibly imagine the state space in the future. We can't hope to imagine all of the possible states of being that could be created in the future and we don't know now which relevant factors we have left out (Ramírez and Ravetz, 2011). Certainly this places a limit on our ability to model adaptive capacity – how can we model something when we can't define the possible state space? Perhaps this is one of the reasons there are so few formal mathematical models of adaptive capacity within the resilience literature. This type of uncertainty/unknowability is an unavoidable part of the human condition.

It is important to remember that, while we can go some way to reducing and quantifying uncertainty with data and models, there will always be unavoidable uncertainty and unknowability.Thus, while modeling can help a great deal with building and managing resilience, it can never be our only tool.



4.

An Interdisciplinary Framework for Resilience

4. An Interdisciplinary Framework for Resilience

4.1. Reframing Resilience

Based on the analyses and syntheses presented in Chapters 2 and 3, this chapter presents a coherent conceptual framework for resilience, which incorporates the diverse understandings extant in the literature, while being clear and internally consistent enough to permit direct mathematical formulation. The associated mathematical framework is demonstrated by examplein Chapter 7.

Across all disciplines, sectors and social worlds, resilience relates to the response of a system to disturbance or change, whether that disturbance is sudden and shocking or more gradual. When a system is subjected to disturbance, there are only three possible outcomes: it withstands the disturbance maintaining fixed values of the features of interest; it does not maintain fixed values of the features of interest but is able to recover them in an acceptable timeframe; it does not maintain fixed values of the features of interest and does not recoverthem, but ends up in a different conditionfollowing disturbance. Each definition in the resilience literature describes one or more of the following three types of behavior:

1. Robustness/Resistance: absorbing the disturbance and maintaining the values of certain variables/properties; ability to resist change.
2. Stability/Recovery: Recovering from the disturbance and returning to the original values of certain variables/properties.
3. Adapting/Benefiting: adapting as a result of the disturbance and moving to a new state that is at least as desirable as the original, potentially more so.

If a system is able to withstand disturbance, it will be called resilient; if a system is able to recover from disturbance, it will be called resilient; if a system is able to improve following disturbance, it will be called resilient. The only response to disturbance that is not considered resilient is when the system changes to acondition that is less desirable than where it was prior to the disturbance.

There has not been a progressive expansion from robustness to encompass more of these elements over time. There has not been a linear development and different sectors have not matured in the same way. All three types of behavior are still currently in use in isolation and in combination under the name of resilience. Resilience practitioners each have their reasons, which make sense in their context of application, for adopting a particular understanding of resilience in terms of one or more of these types of behaviour. In order to communicate and collaborate in interdisciplinary, inter-sectoral and inter-agency settings, it is useful to adopt a definition of resilience that incorporates all three types of behaviour as ways that a system can handle change without undesirable outcomes. This avoids potentially heated arguments about resilience being only robustness (for those who have reasons to think that, if certain features are not maintained, the system is not resilient); or recovery (for those who can tolerate change in features of interest in the immediate aftermath of disturbance but need those features to be recovered in an acceptable time frame);or (for those who have reason to argue that resilience must be different from just robustness, stability and recovery) about our ability to be flexible and learn, grow, change and benefit from disturbance. All three types of behaviour are strategies for dealing with disturbance and avoiding transition to an undesirable state. Including all three types of response is consistent with Holling'soriginal seminal definition of resilience as the capacity of a system to absorb and utilize and possibly even benefit from disturbance(Holling, 1973).

Trade-offs exist between the three types of response to change (absorbing/resisting, stability/recovery, adapting/benefiting)described above, both within and across system scales, and across types and scales of disturbance. For example, building robustness at one scale can lead to a lack of flexibilityat larger system scales. This also applies for larger disturbances at the same system scale; for example, building robustness to sea-level rise by increasing sea-wall height can increase the fragility of the system to sea-wall over-topping or collapse. Conversely, large adaptive capacity at small system scales can lead to a lack of stability at larger scales that, in some cases, could be undesirable. Also, collapse on one scale might be considered adaptation or resilience or adaptation at larger scales.

Resilience is normative in that it relies on the definition of desirable versus undesirable features (either states or system properties). The notion of desirability, or benefiting from change, is repeated throughout conceptual, empirical and mathematical resilience literature. The value judgement of what is desirable and what constitutes improvement or detriment is observer dependent. Changes that benefit one stakeholder may be detrimental to another. Who gets to define what is desirable and what is beneficial? A change that is desirable to one stakeholder may be detrimental to another. This raises some very interesting challenges to operationalizingresilience in practice and directly points to a number of ethical considerations, particularly in the development and resource management sectors, where what constitutes development or improvement, for whom and by whom, has predominantly been decided by the haves and not the have-nots.

Where system boundaries are drawn, what is included in the analysis, which features of the system are allowed to change and which must be preserved, and what sorts of change constitute improvement within those boundaries, completely determines what is interpreted as resilience, adaptability, vulnerability or collapse and so forth.

Consider, for example, the ancient Mayan Civilization. In the book,Collapse, Jared Diamond cites the Mayan Civilization as an archetypal example of collapse, since the urban settlement-based society changed leaving a legacy of abandoned infrastructure (Diamond, 2005). However, a response to this book, titled Questioning Collapse, argues that the Mayans adapted rather than collapsed (McAnany and Yoffee, 2009). The book provides evidence that it was a conscious decision on the part of the Mayan people to decentralize and migrate, and that this was a sustainable decision since their resource base is distributed. Their descendant populations persist in this way today and hence it is argued that this case constitutes adaptation and resilience rather than collapse (McAnany and Yoffee, 2009). This example highlights the importance of the definition of the boundaries of the system under consideration, desirability of features, which features need to be preserved and which can be changed. The interpretation of resilience is thus highly dependent on perspective and values for any particular system.

The type of disturbance is also important. Systems can be very resilient to one type of disturbance but vulnerable to another. For example, Mumbai slum dwellers have developed strategies for coping effectively with year-on-year flooding; however, they do not have the capacity to cope well with the outbreak of a viral epidemic. Figure 4.1 is a cartoon of typical dark Belgian humour that illustrates this point. The group of animals is saying 'Why have you got a shield, turtle?' and the turtle answers, 'This shield protects me from all danger.'

Figure 4.1. Q: "Why have you got a shield turtle?" A: "This shield protects me from all danger" (Jerome, 2013).

Consider also the example of GoulburnValley in Australia. GoulburnValley is thought of as one of Australia's food bowls. Over the twentieth century deep-rooted native vegetation was cleared and large-scale irrigation systems were set up to handle water shortages. The water table has risen as a result of the clearing. The area now experiences increased rainfall and the capacity of the system to cope with this has been reduced and, as such, is subject to waterlogging and flooding. The changes made to the system to increase robustness to drought have led to increased vulnerability and lack of ability to cope with flooding. Furthermore, reversing these changes is not easy – replacing deep-rooted native vegetation takes a very long time, while soil salinization due to the rising water table has caused irrevocable damage and many of those plants simply can't be put back (Eakin et al., 2009).This example highlights the importance of the type of disturbance under consideration and also the importance of time frame.

Increasing resilience or robustness to one type of disturbance can often lead to increased vulnerability and fragility to other types of disturbance. John Doyle (Doyle et al., 2005) highlights what is called the robust yet fragile nature of the internet: that every time a particular type of disturbance is designed for and overcome, the more heavily designed the system becomes to the known and identified disturbances, the more fragile it seems to become to unknown and unforeseen disturbances in the future. This raises the issue of action taken now to build robustness or stability may reduce adaptive capacity in the future.

This also highlights that resilience is a concept that is meaningless without specification of the timescale under consideration. Timescale determines the relevant disturbances;

timescale also determines whether or not the features of interest have recovered in an acceptable fashion.

Recent work indicates that dinosaurs would not have become extinct if the asteroid had hit a few million years earlier or a few million years later(Brusatte et al., 2014). The time it hit coincided with a loss of biodiversity and, in the context of this, the asteroid was devastating. This is a fantastic example of resilience 'to what, over what time frame' that highlights the significance of multiple interacting stressors. Thinking about the dinosaurs also has interesting implications for 'of what, from whose perspective' since the birds are still with us, and some might argue a case for considering this adaptation.

In summary, resilience is a property of a system that describes the nature of the response of the system to a particular disturbance, of a particular magnitude, from the perspective of a particular observer over a specified timescale. Thus any method we use to characterize resilience qualitatively or quantitatively relies on a clear specification of the scope and scale of the system under consideration, of the measure of improvement or benefit within those boundaries, the type and magnitudes of disturbance to be considered and the timescale to be considered. In order to discuss resilience meaningfully, we have to talk about resilience of what, to what, from whose perspective and over what time frame. These key issues represent a framing cycle, since the system boundaries indicate who is a legitimate stakeholder, and those stakeholders may reframe the relevant system of interest, and the time frame indicates the disturbances that are relevant; consideration of these factors may affect the system boundary judgements and so on.

Figure 4.2. Resilience Framing Cycle.

In any given situation, it will be necessary to clarify what is meant by resilience by specifying relevant disturbances (to what), the boundaries of the system of interest (of what), what constitutes desirable change to whom (which type of behaviour is relevant to which features of the system, what must be preserved, what must recover, what can change in a manner deemed beneficial) and what is the timeframe for analysis.

4.2. Resilience, Interconnectedness and Holism

As discussed in Sections 2.4.1 and 2.4.2, a defining characteristic of taking a resilience approach is acknowledging the fundamental interdependence and interrelatedness of all things(Walker and Salt, 2006). Many authors have written about panarchy and cross-scale and cross-level effects(Gunderson and Holling, 2002), about the need for interdisciplinarity(Folke, 2006, Brand and Jax, 2007), the interaction of multiple stressors(O'Brien et al., 2004) and the multi-consequentialist nature of any intervention aimed at building resilience (Agrawal, 2011).

There is increasing awareness of the links that exist between physical, social, economic, political and ecological systems at all scales(Gunderson and Holling, 2002). Environmental problems, such as climate change, deforestation and biodiversity loss, interact with social problems such as poverty and inequitable distribution of wealth both within and between nations (Mikkelson et al., 2007, Adger and Kelly, 1999, Adger et al., 2005, Ribot, 2009, Midgley, 2000). Shiva and Midgley demonstrate that, as long as the inequitable distribution of wealth between nations and the net transfer of resources from poor to rich countries continues, governments in poorer countries are likely to resist pressures from those in richer ones to curb unsustainable economic growth(Midgley, 2000, Shiva, 1990). Global environmental problems also interact with personal ones(Grothman and Patt, 2005, Stern, 1992). In many societies, ethical decision-making is increasingly being delegated to the level of the individual, but, unless wider social and organizational change is undertaken to put in place the systems and infrastructure that support this, people will find themselves more and more regularly in the stressful situation of striving and failing to reconcile competing personal, familial, social and ecological demands(Gregory, 1992). The author has personally found this in her struggle to make her household zero waste which involves creating entirely new production, supply and consumption systems to circumvent the packaging-intensive external environment, and she has found that she does not always have the time, energy, skills and funds to succeed.

These cross-scale, cross-sector, cross-discipline links make the setting of boundaries, when seeking to understand or to intervene, difficult and often highly contentious. Further, as discussed in Section 4.1, the way system boundaries are drawn around scope, scale and timeframe– and which disturbances are being considered– determines what will be considered resilience or adaptation versus vulnerability or collapse. Where boundaries are drawn, and what constitutes desirability and improvement within that context, for whom and by whom, also determines the conclusions and recommendations for actions that are drawn (Ulrich, 1983). Midgley demonstrates that it is only by being open to exploring the boundaries of issues from global environmental issues to local homelessness, and encouraging the participation of diverse stakeholders, that a variety of possible angles can be covered, and unanticipated sideeffects of intervention can be minimized (Midgley, 2000).

Resilience grew out of a desire to be holistic, to avoid the over-simplifications and narrow reductionist approaches that led to poor stewardship of human and natural systems and collapse in the past(Walker et al., 2004, Hughes et al., 2007). According to a widely held understanding of the resilience idea, resilience thinking means an effort to 'look at the whole' of an issue(Walker and Salt, 2006, Folke et al., 2010). That is, to include the entire relevant problem environment in one's definition of a modelling, design or governance problem. This claim to holism is something that has been taken for granted in much of the resilience literature. It has been a very fashionable idea and it represents a self-justifying ideology: that resilience science is comprehensive rather than reductionist.

Werner Ulrich highlights that comprehensiveness and reductionism both rely on the same type of rationality, instrumental rationality, as both strive for unconditional justification (Ulrich, 1993). However, comprehensiveness is challenged because comprehensive thinking on social and ecological issues 'can find no natural boundaries'(Ulrich, 1993). Because of the fundamental interdependence and interconnectedness of all things, a fundamental part of resilience thinking, comprehensiveness would imply expanding our system boundaries to include 'the World and God and everything'– and then being unable to even think about it let alone do conceptual or mathematical modeling –or otherwise be left with a problem that is incompletely specified because we have left something relevant out of the analysis. This is what Ulrich refers to as 'the problem of holism' since 'the holistic imperative of "considering everything relevant" is as philosophically as inescapable as it is impracticable'(Ulrich, 1993).

To a certain extent, this problem seems to have plagued resilience in practice, with some perception that the best resilience thinkers are those with the biggest models. In fact, the larger the model, the more opportunities there are for results to be dominated by mathematical or numerical artefacts, the more parameters there are to estimate and, in general, the more room for error in both formulation, calculation and interpretation. Such large models end up being largely unreliable and meaningless, and the systems thinking and operations research community went through a similar process that lead to the 'death of the super model' in the 1960s (Midgley and Richardson, 2007).

The problem with saying you are going to be holistic is that, while it is a worthy goal, it is unachievable in practice due to the fundamental interdependence and interrelatedness of all things. The quest for comprehensiveness, although it represents an epistemologically necessary idea, is not realizable. We cannot have a 'God's eye view' of everything and all the interconnectedness because there are inevitable limits to our understanding. Those limits we call boundaries. Therefore boundary judgements are inevitable. The notion of system boundary judgements and how to deal with them is discussed in Section 4.3.

4.3. Systems Thinking and Resilience Thinking

The systems thinking literature has the longest tradition of wrestling with interconnectedness, the quest for comprehensiveness and the problem of holism. In the late 1960s, Charles West Churchman, one of the most influential thinkers within the systems movement, asked, 'How can we design improvement in large-scale systems without understanding the whole system, and if the answer is we cannot, how is it possible to understand the whole system?'He answered that we cannot apprehend the 'whole system' in any objective sense, and that we make value-laden judgements about what to include and what not to include, that these choices have power since they determine assessment of improvement, and there is therefore an ethical dimension to how they are made (Churchman, 1968a).

Rittel and Webber coined the term 'wicked problem' to describe situations where our understanding of the problem changes through the process of analysis and attempting solution, where attempted solutions reveal or create other problems due to the interconnectedness of everything, where all of these phenomena have many levels of explanation and the type of explanation suggested determines the knowledge generated and the further solution attempted (Rittel and Webber, 1973). Understanding and managing the resilience of human and natural "systems" to change is certainly a wicked problem.

Those involved in understanding or modelling human and natural systems make judgements about what is important to include in the analysis and what can be delegated to the system environment. Thesejudgements are influenced by their education and disciplinary backgrounds, their social and cultural values, their purpose in conducting the analysis and a range of intangible factors. That is, what belongs to the 'whole system' is entirely dependent on and relative to the inquirers choice of conceptual boundary (Ulrich, 1983). As such, whenever we speak of a system, it should be obvious that we are not speaking of transcendent reality (Matthews, 2004) . In Ulrich's words,'It is not the reality "out there" that determines the boundary between the system and the environment, but rather the inquirer's standpoint, the purpose of his mapping effort, his personal preconceptions of the reality to be mapped and the values he associates with it'(Ulrich, 1983).

Figure 4.2 shows someone who has formulated or distinguished a system of interest in a situation. In the process, a boundary judgement is made which distinguishes a system of interest from an environment. Because we each have different perspectives, interests, histories and so forth, it is likely that we will make different boundary judgements in the same situation, i.e.my education system will be different from yours because we see different elements, connections and boundaries. Different stakeholders often frame issues in different ways and make different sets of system boundary judgements and have different measures of improvement within those boundaries. Furthermore, when it comes to justifying the merit of plans, adaptation planners can only ever refer back to the context of application – the original whole system judgement. This explains, for example, why there are so many disparate views about the existence of, causes of and means to address climate change (Hulme, 2009).

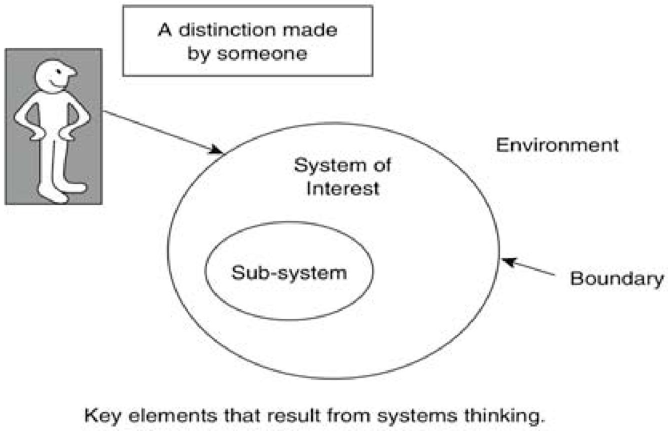


Figure 4.3. System boundaries are inevitable and normative (Ison, 2008).

The system boundary judgements made inform the systems models subsequently developed and, therefore, our understanding of that portion of the "real" world (Churchman, 1968b). Moreover, as discussed, these boundary judgements also determine what will be defined as resilience or adaptation versus degradation or collapse.

Vickers notion of 'appreciative system' draws attention to the fact that appreciative systems (i.e. norms values and so forth) can be very different to those of the external expert (Vickers, 1965). Vickers argued that our human experience develops within us a propensity to notice particular aspects of our situation, to categorize them in particular ways and to measure them against particular standards, norms or values of comparison. This experience-based system of understanding the external world around us is the 'appreciative system which creates for all of us, individually and socially our appreciated world' (Checkland, 1981).

Systems thinkers are carefulto point out that systems are conceptual entities that have no physical existence (Checkland, 1981). While systems are conceptual entities, they can be used to understand and model human experience of the world through a process of idealization and representation (Midgley, 2003). In circumstances in which there seems to be a close resemblance between the model and its subject, there will be a tendency to mistake one for the other– a phenomenon that may have significant consequences. Kline coins the term, 'Korzibski's Dictum', to refer to this issue; Korzibski's Dictum is 'The map is not the territory' (Kline, 1995). This seems to be the case with some ecologists, who think ecosystems are concrete entities that exist rather than ways that humans make sense of the organization of the natural world.

The systems thinking literature has wrestled directly with interconnectedness, the quest for comprehensiveness and the problem of holism for at least 40 years longer than the resilience community, most of which still does not openly acknowledge the subjectivity of system boundary judgements even though this is an inherent implication of the ontology of interconnectedness it adopts. Given the underpinnings of resilience in an ontology of interconnectedness, the real challenge posed by the resilience idea is not that, in order to be rational, we need to be comprehensive but, rather, that we must learn to deal critically with the fact that we never are– we can't be.

Accepting that boundary judgements are inevitable, normative and affect our conclusions and recommendations for action about resilience, implies that we should progress with humility, in a reflective and iterative manner that involvesall those whose lives might be affected in whatever intervention we might propose. The participation of the affected is an ethical requirement, given that resilience thinkers cannot rest on undefendable claims of objectivity or comprehensiveness. It is also a practical requirement, since it is only by being open to exploring the boundaries of issues from global environmental issues to local homelessness, and encouraging the participation of diverse stakeholders, while capturing and effectively communicating uncertainty, that a variety of possible angles can be covered, and unanticipated negative sideeffects of intervention can be minimized(Midgley, 2000).

This necessitates the use of participatory methods for adaptation planning and decision-making. Furthermore, since we can only ever have a partial view of the relevant problem context, there will always be some unanticipated consequences of any intervention. Accordingly, our approaches must be reflectively assessed and improved through an iterative process of feedback loops. This understanding forms the basis of the reflective, iterative, participatory approach to operationalizingresilience advocated in this thesis. The following section will translate all of this into a coherent conceptual framework for system resilience.

4.4. Conceptual Framework

4.4.1. System

This thesis adopts a position of ontological neutrality and epistemological humility. It takes the minimal realist position that something exists, but also maintains that our experience and knowledge of whatever exists is mediated by the physical and mental apparatus that we possess as humans, or as Kant would put it: 'we have no knowledge of things in themselves' (Kant, 1787). This is consistent with the contextualist position that 'interconnectedness is an intrinsic feature of the world' (Matthews, 2004) that underpins resilience thinking, as discussed in Chapters 2 and 4.

Contextualist literature illustrates that we select certain 'contexts' out of the interconnected mass of everything, that these contexts act as organizing frameworks and highlight a vast array of features that would not be visible without the organizing framework, and that another selection would lead to different insights (Lilienfield, 1978). The selection of 'context' creates structure, meaning and insight. Since contextualism denies that parts and wholes are absolute categories, it claims a kind of ontological neutrality about the structure of the world (Quine, 1969). According to Matthews,'most contextualists would deny that the world has an intrinsic structure that can be grasped – preferring to assume that it is irreducibly interconnected'(Matthews, 2004).

This all has implications for the definition of system. In simple language, the world is composed of a whole lot of interconnected stuff[1] and systems are ways that we divide up, idealize and make sense of this world of interconnected stuff. Systems are not concrete

[1] The author has deliberately chosen the word, 'stuff', to avoid the baggage of words such as items or things which imply distinct/individual components rather than a mass of interconnectedness.

entities that exist independently of mind, and their boundaries are given objectively and unproblematically by the structure of reality.

Systems are subjectively defined. They necessarily depend upon a variety of choices made (both consciously and unconsciously) by the system modeller(s) including their purpose of inquiry, educational background, socio-cultural context, values, personality, the types of theories and methods they plan to use and so on. The noun 'system' has its roots in the Greek word 'synhistanai' that means 'to stand together'(Ison, 2008). The fact that the word,'system', is now commonly defined as a noun rather than a verb is indicative of how systems are considered in common language to be things that exist, real world entities; however, this position does not bear analysis (Ulrich, 1983, Ulrich, 1993, Midgley, 2000, Midgley, 2003, Matthews, 2004).

A system isan idealization of certain features of human experience of the world as a complex whole. 'A system is a perceived whole whose elements are "interconnected"' (Ison, 2008). A system is an abstraction that has no physical existence (Checkland, 1981). There are infinitely many ways the world can be divided and idealized as systems (Midgley, 2000)

4.4.2. Boundaries and Scope

System boundaries are a set of criteria that distinguish what is in a system from what is not.

Social, economic, political, environmental and physical issues are connected across scales and levels. Within any specific issue, one finds connectedness to all other issues (Churchman 1982). System boundary judgements are inevitable due to this interconnectedness and the inescapable limits on our ability to have a God's eye view of everything in the entire universe, from the infinitesimal to the immense to the massive and all of the complex interconnections therein.

System boundary judgements are subjective and depend upon the purpose of the inquiry, the social, cultural, educational and disciplinary background of the inquirer(s), by their values, the institutional context of the inquiry, the methods of analysis and representation to be used, potentially the availability of data, and many other intangible factors (Churchman, 1968b, Churchman, 1968a, Ulrich, 1983, Midgley, 2000). Systems live and breathe because of choices that distinguish them from the interconnected mass of everything and give form, structure and meaning to their existence.

The scope of the system is what is inside the system boundary.

4.4.3. Scale, Level, Scope and Extent

The terms scale, level, scope and extent are used interchangeably in academic and grey literature as well as in common language. There are many different, and often contradictory, definitions of these concepts extant across both literature and practice. For example, according to the Oxford English Dictionary, scale can refer to 'the size of something' or to the analytical dimensions and units used to understand or measure it, such as the scale on a ruler or map [2] (Oxford English Dictionary, 2012).

Following Gibson et al.,'scale' is defined as the analytical dimensions used to measure and study any phenomenon and 'levels' as the units of analysis that are located at different positions on a scale (Gibson et al., 2000). Scales and their associated levels can have physical or purely conceptual meaning. Some thought- provoking examples of scales arising from different disciplines or sectors and the levels on those scales are shown below.

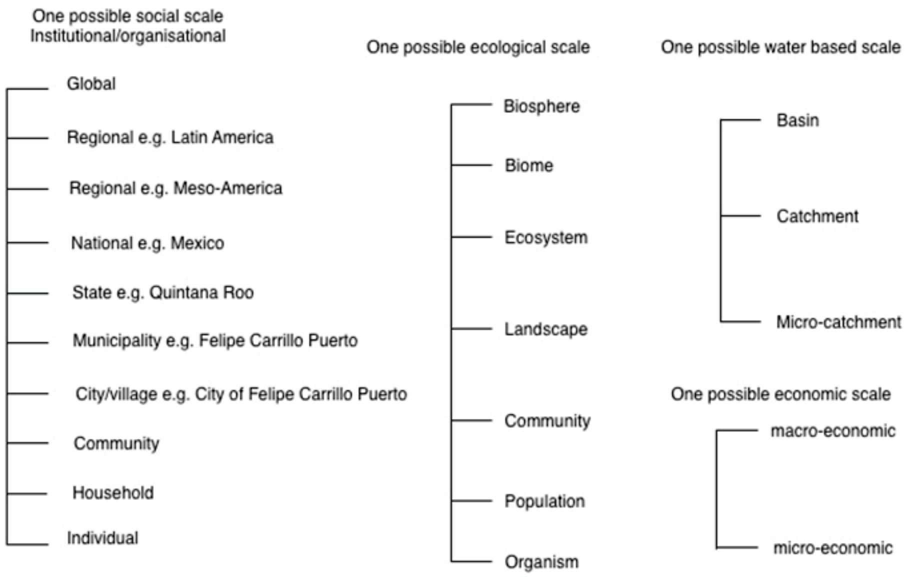


Figure 4.4. Examples of scales and their associated levels. The diagram shows a social organisational scale, an ecological scale, a water-based physical scale and an economic scale. There are no natural scales and levels, these are all human-defined schema.

Consider, for example, the organizational-institutional scale, which shows one possible representation of the structure of social organization for governance and decision-making from global down to intra-community levels in Mexico. The levels on that scale are: global, regional, national, state, municipality, village, community, household, individual. This is not the only possible way of defining such a scale relevant to Mexico. It could be argued that community doesn't even belong on that scale because it is a poorly defined term and a community could, in fact, be made up of people who represent different levels on the rest of that scale. Or it could be really useful to include it if we want to look at different groups or 'communities' within cities or villages, such as ethnic communities within the city of Felipe Carrillo Puerto. An agro-ecological scale could be field, farm, village, catchment, landscape and so forth. There are no natural scales and levels; they are all human-defined schema, which make sense for different purposes and contexts. Any number of scales and levels can be defined to understand notions of structure within different systems.

[5] Or for that matter, scale can refer to the small, thin plates protecting the skin of fish and reptiles, although that definition doesn't usually make it into this discourse. The point is, we are used to words having multiple meanings in common usage, and this doesn't need to be a problem;, we just have to be clear about what we are talking about at any one time (the scales of fish or the scales of fish).

Extent is commonly used to refer to the physical span of a unit of analysis or, in other words, the area covered by something (Oxford English Dictionary, 2012). Geographical extents are often associated with levels on an institutional scale; for example, a state has a defined geographical extent within a nation, which also has a defined geographical extent. Ecological and biophysical levels are also often associated with geographical extents – for example, a forest may cover a certain geographical region and a catchment may cover a certain geographical region. However, not all social, cultural, political, economic or ecological levels map onto geographical extents in sensible ways as described above, or at all for that matter – what is the geographical extent of a person's spirituality? So we will need to also define another term to capture conceptual entities that do not have physical sizes or geographical extents and yet are important for our analysis.

Scope is defined as an abstraction of extent thatincludes items that do not have physical size. Something is within the scope of the study if it is included in the analysis and outside of the scope of the study if it is not, irrespective of whether it has physical or geographical dimensions. For example, if gender and religion are being considered, then gender and religion are within the scope of the study. If the impact of earthworm populations on soil quality in a defined area are being considered, then that area, its soil and earthworm populations are within the scope of the study, and, if the sanitation habits of people in the same area are not being considered in that study, then they are outside the scope – even though they may well impact on soil quality. The scope of the system thus refers to that which is within the boundaries of the system, be it conceptual, physical otherwise categorized. An example of scope that has no physical or geographical extent would be the set of all negative integers between -1 and -25, or the set of all ideas that have originated on the toilet.

Frequently in common usage the term,'scale', is mixed up with extent when people refer to 'the size or scale of something'. In fact, the terms,'scale' and 'level', are often used interchangeably with each other and with the concept of extent. If the word,'scale', is used to refer to the concept of extent, this leaves no natural terminology to describe the other concept of scale, which is only ever referred to as scale. Thus, for completeness and consistency, we use scale, level, extent and scope as defined here. Gibson et al. highlight that the levels on a scale can be, but are not necessarily linked to each other in a hierarchical order (Gibson et al., 2000).

Note that there are frequently mismatches between different scales, levels, scopes and extents. For example, the institutional level responsible for catchment management is often the state (sub-national). A catchment is a level on a biophysical scale rather than an institutional scale and a catchment may span multiple states creating a mismatch between institutional and biophysical scales, levels and extents. An ecosystem can be a level on an ecological scale as shown above. A single forest ecosystem could span multiple catchments creating a mismatch between ecological and biophysical scales, levels and extents. This is further complicated if the management of the forest is spread across different state boundaries and the management of the catchment is done by a different set of departments again, adding institutional mismatch to the mix.

There are complex interactions between phenomena across scales and levels that can be logically pulled apart and examined using the conceptual framework of scales, levels, scopes and extents described here. Certain phenomena may be identifiable only at particular levels on a scale and not at others, and conscious effort is required to triangulate methods and data to examine trade-offs across scales levels and extents. For example, trade-offs between diversification at the farmlevel versus at the landscape level on an agro-ecological scale, or trade-offs between stability and adaptive capacity between scales and levels.

4.4.4. Identity

Identity is defined by the set of features of a system that are thought to make it what it is, as opposed to something else. For example, there are features of a coral reef that make it a coral reef as opposed to a tropical rainforest, which has its own set of identifying features.

Identity can be modelled as particular ranges of values of key variables or system properties. For example, perhaps there has to be some live coral, which has to be covered by seawater some of the time, for something to be considered a coral reef. Other things can change but these two features need to be there. Perhaps there has to be a lot of trees and a lot of rainfall as well as reasonably high temperatures for something to be considered a tropical rainforest.

Classes of identity are often shared social constructions. Humans have defined what makes certain ecosystems, political systems, economic systems, physical systems what they are, as opposed to something else.For example, what differentiates a tyrannical regime from a democratic one. Needless to say, there are frequent disputes. Ascribing the features that define identity can be highly controversial and contested. What is it that makes us human? What are the vital features required for someone to be considered Australian? What are the vital features required for someone to be considered a Muslim?

Ascribing the features that define identity is difficult and, for any given set of criteria, assigning individuals to a particular class is often highly problematic, even in highly scientistic contexts such as assigning individuals to taxa. This is because there can be as much variability in different dimensions within classes as across them.

There is a risk that members belonging to a particular class will be assigned characteristics that belong only to a few members, and this oversimplification can lead to hatred and violence. Just because someone is Islamic, Jewish or Christian doesn't mean they will support a particular political view held by some members of those groups. In the book,Identity and Violence,AmartyaSen highlights that all people belong to many groups, and there is no one single unique way of partitioning all of humanity into distinct, discrete groups, which is always most important in any given context (Sen, 2007). It is quite possible for someone to be a male British citizen, of Malaysian origin, with Chinese heritage, who is heterosexual, supports gay rights and is a vegetarian and an engineer.

Sen points out that which one of these 'identities' is most important depends on context (Sen, 2007). There is a group of Israeli and Palestinian women who all belong to the group 'mothers who have lost their sons in the Israeli-Palestinian conflict', who find their shared identity of having lost their sons more powerful than their other group memberships and who work together for peace. Pakistani and Indian ecologists work together to manage snow leopard populations. Gay people all over the world will unite to defend civil rights.

Sen also highlights that marginalization often manufactures identity (Sen, 2007). The set of all people born between 9am and 10am local time all over the world currently have no reason to consider themselves a group and have a shared sense of identity – unless someone sets about killing everyone born at that time, in which case they would certainly have reason.

Sen and systems thinking teach that there are infinitely many ways to divide up and make sense of our world, including the definition of identity associated with such divisions. While there is knowledge to be gained from such a process, there are also limitations and dangers associated with these divisions and attributions of identity if we come to see them as fixed and rigid classes, unquestionable, solid and objectively representative of the structure of reality. Such a way of making sense of the world ispart of the human condition; however, we should acknowledge the subjectivity and limitations of our categories and be open to rethinking them, and allowing for pluralism in our categories and notions of identity. This will have important implications for resilience.

4.4.5. Components and Structure

A component is a constitutive element of a system; a system is a set of interrelated components. The structure of the system is the topography of these relationships.

4.4.6. System Status, State and Properties

The status of a system is a particular condition of its existence at any given time–put more simply, how it is.

A state of a system refers to the values of 'state variables'. The definition of state variables is a modelling choice.

A state vector is a vector with components that are the state variables used to represent a system's states for given modelling assumptions.

A state of a system (or system state) is represented as an instantiation of its state vector.

The state space of a system is the set of all possible instantiations of its state vector.

System properties are features of interest that depend on the state space and, in modelling terms,are calculated as functions on the state space,(see Chapter3).

Status can include the values of both state variables and system properties, as status just describes the condition of the system.

4.4.7. State change

A state change is a change of instantiation of a state vector.

The start and end states of a state change are respectively the initial and final instantiations of the state vector for that state change.

A reversible state change is a state change,the start state of which can be returned to directly from its end state. An irreversible state change is a state change,thestart state of which cannot be returned to directly from its end state.

A recoverable state change is a state change, the start state of which can be returned to either directly or indirectly from its end state. It follows that all reversible state changes are recoverable. An irrecoverable state change is a state change, the start state of which cannot be returned to either directly or indirectly from its end state. It does not follow that all irreversible state changes are irrecoverable.

A state trajectory is a sequence of state changes. Sequences in state trajectories are often indexed by time but this is not necessarily the case.

A reversible state trajectory is a state trajectory, the start state of which can be returned to directly from its end state. It follows that all state changes in a reversible state trajectory must be reversible. An irreversible state trajectory is a state trajectory,thestart state of which cannot be returned to directly from its end state. A state trajectory containing an irreversible state change must be irreversible.

A recoverable state trajectory is a state trajectory, the start state of which can be returned to either directly or indirectly from its end state. It follows that all reversible state trajectories are recoverable. An irrecoverable state change is a state trajectory, the start state of which cannot be returned to either directly or indirectly from its end state. It does not follow that all irreversible state trajectories are irrecoverable.

A circular state trajectory has the same start and end states.

4.4.8. Equilibrium

A system is in (partial) equilibrium with respect to a system variable or property while the value of that system variable or property does not change.

A state vector is in complete equilibrium while its instantiation does not change, i.e. while the state of the system represented by the state vector does not change.

4.4.9. Function

A function of a system is an aspect of its behaviour considered by the modeller to have some purpose; it is part of what the modeller considers the system to do.

4.4.10. Dynamics and Feedback

The dynamics of a system are its patterns of change over time.

A mode of a system is a particular pattern (or set of patterns) of its changes over time [3].

A mode may repeat over time. The period of a mode is the time interval between its successive repeats. Periods may be finite or infinite.

System dynamics is a general concept that encompasses all aspects of a system that can change with time. However, particular aspects of change can be considered in isolation, e.g. state, structure, function, properties, identity, etc., giving rise to more specific dynamical concepts, such as the following.

The (state) dynamics of a system are its patterns of state change over time [4]. The dynamics and (state) modes of a system are often represented in terms of state trajectories.

The structural dynamics of a system are its patterns of structural change over time. Structural dynamics pertain to how the relationships between the components of a system change over time.

The functional dynamics of a system are its patterns of functional change over time. Functional dynamics pertain to how what a system does changes over time.

Feedback is a causal mode in which a system's current and/or past states and/or system dynamics influence its future states and/or system dynamics.

4.4.11. Transformation

The identity of a system cannot be changed without the system ceasing to be what it was and becoming something else, by definition. Accordingly, transformation is a change in the identity of the system.

Transformations can be considered to be desirable, or otherwise, depending upon the modelling assumptions and/or the values of the observer. So, for example, a system that has transformed can be said to 'have died', 'have lost its integrity', 'been destroyed', 'have failed', 'been re-born', 'replaced', 'revised', 'refined', 're-modelled', 'corrected', 'updated', etc.

4.4.12. Restructuring

Potentially, depending on how identity is defined, a system can change its structure without changing its identity.

[3] Thus, the dynamics of a system is the power set, i.e. the set of sets, of the system's modes.

[4] Note that in this work when the term dynamics is used without a qualifying term such as functional it should be interpreted as an abbreviation for the term state dynamics.

Restructuring is the process by which the structure of a system is changed without any change to the identity of that system. Restructuring can be considered to be desirable or otherwise, depending upon the modelling assumptions and the value system of the observer. So, for example, a system that restructures can be said to have 'been damaged', 'evolved', 'undergone revolution', 'been reorganised', 'improved', 'progressed', 'crippled', etc.

4.4.13. Transition

A system can change its dynamics without changing its identity or structure.

Transition is the process by which the dynamics of a system are changed without any change to the identity or structure of that system. Transition can be considered to be desirable, or otherwise, depending upon the modelling assumptions and the value system of the observer.

4.4.14. Adaptation

Adaptation is a process where a system undergoes change in response to experienced or anticipated stimuli. This response can be conscious/intelligent or unconscious/self-organizing, proactive or reactive. Many authors specify types of change in terms of structure, function, and feedback. However, in order to be consistent and coherent across literature and example of adaptation, this conceptual framework will adopt a definition of adaptation that anything can change except for the identity of the system because, if identity changes, this is transformation and not adaptation by definition. Therefore, adaptation can involve changes in state, structure, function, feedbacks, anything except identity.

Classification of a system response as adaptation versus other types of change, such as transformation, is sensitive to specification of system boundaries, identity, types of disturbance and time frame for analysis. Adaptation can be judged as positive or negative based on preferences for desirable states, properties or features of a system from the perspective of a particular observer. Often the term,'adaptation', is used when the system change is judged to be positive and maladaptation when it is judged to be negative. The difference between classification as adaptation and maladaptation is sensitive to notions of desirable change. Altogether classification of adaptation depends upon specification of adaptation 'of what, to what, from whose perspective and over what time frame'.

Ryan highlights that there are three essential functions for an adaptive mechanism: 'generating variety, observing feedback from interactions with the environment, and selection to reinforce some interactions and inhibit others. Without variation, the system cannot change its behaviour, and therefore it cannot adapt. Without feedback, there is no way for changes in the system to be coupled to changes in its environment. Without preferential selection for some interactions, changes in behaviour will not be statistically different to a random walk. […] The adaptive system does not need to understand the system dynamics of its environment to adapt. Stimulus response interactions provide feedback that modifies an internal model or representation of the environment, which affects the probability of the system taking future actions. […] From an information-theoretic perspective, variation decreases the amount of information encoded in the system, while selection acts to increase information. Since adaptation is defined to increase mutual information between a system and its environment, the information loss from variation must be less than the increase in mutual information from selection'(Ryan, 2007)

4.4.15. Complexity

Like resilience, complexity has a multitude of definitions and measures, all of which highlight different aspects of the concept relevant for different practitioners and purposes. It is useful to think of complexity in terms of four characteristics discussed by Page: diversity, connectivity, interdependence and adaptation (Page, 2011).

In keeping with this, Ryan proposes a definition of complexity of a system as the total amount of information required to describe the system and its structure, dynamics, feedbacks etc(Ryan, 2007). This definition is related to Ashby's definition of complexity as the quantity of Shannon information required to describe a system, although it is broader (Ashby, 1973).

4.4.16. Emergent Properties

An emergent property of a system is a property that cannot be understood by examination of its constituent parts and that is observed only when examining the whole, not the components in isolation.

In 1875, Lewes introduced the terms 'resultant' and 'emergent', claiming that: 'The emergent is unlike its components in so far as these are incommensurable, and it cannot be reduced either to their sum or their difference'(Lewes, 1875).

4.4.17. Robustness

The robustness of a system is its ability to retain pre-disturbance conditions in the face of disturbance. That is, its ability to resist changing values of state variables, system properties, and to resist changes in structure, function and identity in response to stimulus.

4.4.18. Stability

The stability of a system is its ability to remain in or return to pre-disturbance conditions after being exposed to a particular disturbance.

4.4.19. Adaptability and Adaptive Capacity

The adaptability or adaptive capacity of a system is its ability to undergo adaptation. That is the capacity of a system to change anything but its identity in response to experienced or anticipated stimuli. This response can be conscious/intelligent or unconscious/self-organizing, proactive or reactive. Three capacities are required for adaptability/adaptive capacity: capacity to generate variety, capacity to observe feedback from interactions with the environment, and capacity to select to reinforce some interactions and inhibit others. Without the ability to generate variation, the system cannot change its behaviour, and therefore cannot adapt. Without feedback, there is no way for changes in the system to be coupled to changes in the environment. Without preferential selection (this can be conscious choice or an unconscious mechanism), the changes will not be statistically different from a random walk. Development of adaptive capacity can therefore be achieved by developing the required three capacities.

4.4.20. Resilience

Resilience is a property of a system that describes the response of that system to a particular disturbance, of a particular magnitude, from the perspective of a particular observer, over a specified timescale.

Resilience is the capacity of a system to manage disturbance by resisting change (robustness), recovering from change (stability), or adapting and benefiting (adaptability judged as beneficial) as a result of change. All three types of behaviour are included in the definition of resilience in this conceptual model, as all three types of behaviour are ways of managing change and avoiding negative outcomes. During the process of managing disturbance, any aspect of the system can change except identity and the system will be considered resilient. If the identity of the system is changed, the system is transformed by definition and this is no longer resilience of the original system [5].

Extending this notion to the situation where systems are transformed into new systems that are equally or more desirable than the original, when the original system becomes untenable, gives the notion of meta-resilience. We are no longer talking about the resilience of the original system, as it has ceased to exist, so meta-resilience refers to resilience across systems rather than resilience of systems.

Classification of a system response as resilience or adaptation versus transformation, vulnerability or collapse depends upon definition of system boundaries, types of disturbance, notions of desirability and identity, and the time frame for analysis. Meaningfully discussing, or measuring resilience requires specification of resilience 'of what, to what, from whose perspective and over what time frame', as shown in Figure 4.1.

4.4.21. Transformability

The transformability of a system is the capacity for a fundamentally new system to be created from that system when conditions make that system untenable. Transformability is thus the ability of a system to undergo transformation.

4.4.22. Integrity

The integrity of a system with respect to a given stimulus is its ability to retain its identity when exposed to that stimulus.

[5] This can imply that the more rigid and narrow the conception of identity, the less resilient the system is to change.

Integrity is thus the ability of a system to avoid transformation when exposed to a stimulus.

Adverse consequences may or may not be incurred by a system with integrity responding to a stimulus and retaining its identity.

4.4.23. Sensitivity

A system has sensitivity with respect to a given status and given stimulus if a significant change in the status of the system occurs when the system is exposed to that stimulus.

4.4.24. Exposure

The exposure of a system to a particular disturbance is a measure of the frequency and magnitude of occurrence of that type of disturbance.

4.4.25. Vulnerability

The vulnerability of a system to a particular disturbance is a combination of its sensitivity in a negative way, and exposure to that disturbance. A system may be very sensitive to a particular type of disturbance but, if it is not exposed to it, it is not vulnerable to it. Also the system must be sensitive in a way that is considered undesirable. If a system is exposed to a disturbance that results in beneficial change to that system, it would not be termed vulnerable. Thus, like resilience, vulnerability is a concept that requires us to specify 'vulnerability of what, to what, from whose perspective and over what time frame'.

Vulnerability is sometimes considered the antonym of resilience because the vulnerability of a system, with respect to a stimulus and relative to an observer, is the system's inability to respond to that stimulus without changing in a way that is considered detrimental by that observer. Resilience, on the other hand, is the ability of the system to respond to that disturbance without detrimental impact.

4.4.26. Hazard

Relative to a modeller, a hazard to a system is a stimulus that would, if the system were to be exposed to it, cause that system to change in a way that is detrimental to that system.

4.4.27. Risk

The risk is the product of probability of exposure and the impact of exposure. Risk is a large and highly mathematical field of research. Risk is associated with the calculation of probabilities, whereas vulnerability assessments are often far more empirical and community based.

4.4.28. Attack

An attack on a system is a deliberate attempt to expose that system to a hazard.

4.4.29. Fragility

Fragile systems undergo sudden and catastrophic transformation in response to certain stimuli. The fragility of a system is its capacity to undergo catastrophic transformation.

4.4.30. Protection

If a system is vulnerable with respect to a stimulus, it may be possible to remedy this by augmenting the original system withprotective features that shield it from the stimuli (for example seawalls in the Netherlands) and thus reduce the likelihood of exposure (Holling, 1973).

4.4.31. Critical Features

A feature of a system is critical to that system if the identity of the system is crucially dependent upon it, i.e. its destruction necessarily results in the transformation of the system.

The criticality of a component is not an inherent property of the component but a consequence of the role that it plays within the system.

Systems that have critical features are inherently vulnerable. Such vulnerability can be reduced or overcome by changing the system so that the integrity of the system is no longer crucially dependent upon the previously critical features. This can be achieved by, for example:

- Shielding critical features with protective features.
- Introducing redundancy into the system by diversifying the means by which the function of the previously critical features can be achieved. In some instances, but not all, this can be achieved by replicating the previously critical features.
- Introducing fail-safe features into the system such that the failure of previously critical features does not result in a catastrophic transformation but a 'graceful'change and even transformation.

4.4.32. Safety

The safety of a system with respect to a hazard and relative to an observer is the absence of risk to that system due to that hazard as perceived by that observer.

Thus, an observer will consider a system to be safe with respect to a hazard if the risk to that system from that hazard is considered to be acceptably low. Conversely, an observer will consider a system to be unsafe with respect to a hazard if the risk to that system from that hazard is considered to be unacceptably high.

4.4.33. Security

The security of a system with respect to an attack and relative to an observer is the absence of threat to that system due to that attack as perceived by that observer.

Thus, an observer will consider a system to be secure with respect to an attack if the risk of an attack is considered to be acceptably low. Conversely, an observer will consider a system to be insecure with respect to an attack if the risk of that attack is considered to be unacceptably high.

4.4.34. Versatility

The versatility of a system is its ability to perform more than one function.

4.5. Conclusions

Building on the review, critique and synthesis presented in Chapters 2 and 3, this chapter has presented a coherent conceptual framework for system resilience that is abstract enough to accommodate the diverse understandings of the concept extant across disciplines, sectors and social worlds, while being precise enough to allow rigorous mathematical formulation, which will be covered in Chapter 5.

The conceptual framework presented here not only provides the basis for the operational methodology for understanding, measuring and building resilience in practice which is presented in the subsequent chapters, but also necessitates critical, iterative and reflective approaches to operationalizing resilience.Given the underpinnings of resilience in an ontology of interconnectedness, the inevitability and subjectivity of system boundary judgements, and the dependence of any notion of resilience on them, the real challenge posed by the resilience idea is not that, in order to be rational, we need to be omniscient but, rather, that we must learn to deal critically with the fact that we never are.

Yet, these difficulties cannot paralyze us, or, as Kant would put it, 'We cannot, by complaining about the narrow limits of our reason, escape the responsibility of at least a critical solution to questions of reason'(Kant, 1787). However, the whole concept of resilience also shows us we cannot rest on unjustifiable claims of objectivity.

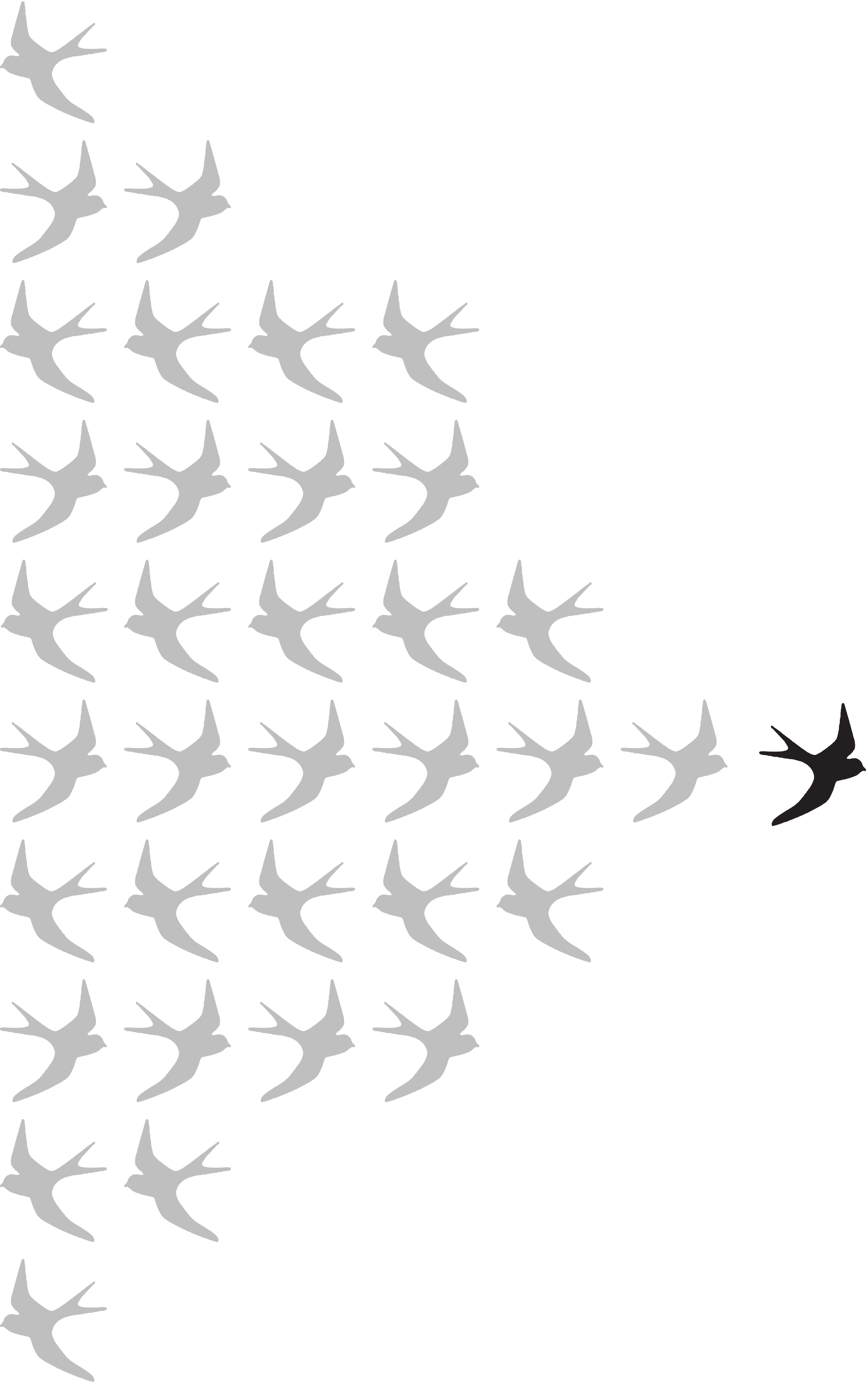
Framing any meaningful work on resilience in practice comes down to the challenge of explicitly agreeing with any group of stakeholders on:

- What is meant by resilience in terms of the three types of behavior discussed?Should actions aim to build robustness, stability or adaptive capacity?
- What are the boundaries of the system of interest (resilience of what):which social, cultural, technical, economic, political or ecological factors will be included in the analysis?
- Which disturbances are relevant to include in the analysis (to what)?
- Which features of the system need to be preserved,which features can change, and what sort of change is desirable, lest the system be judged to have collapsed, transformed or transitioned into an undesirable 'state'?What is desirable and what is undesirable to whom(from whose perspective)?
- What is the timeframe for analysis and planning (over what timeframe)?

This means, getting together and working out the'of what, to what, from whose perspective and over what timeframe'.Given the differences of opinion on these topics that exist in any real world problem, this raises further questions such as:

- Who ultimately gets to decide the answers to these framing questions and how will they be decided?
- Whose interests should be served by any proposed resilience intervention, who gets to decide this and how?
- Who is and who ought to be considered a professional or an expert? What forms of knowledge (scientific/local/traditional) are sought in the process?
- Which worldviews are dominant and which others are atleast taken into account?

Furthermore, once all of these normative judgements have been made explicit, how are they justified and how do we choose between normative judgements when there is a conflict? Often choosing between policies, designs and actions is a matter of choosing between systems of value, since what is 'good' and what will be your measure of success depends on frame of reference. Chapter 6 will describe a methodological framework for dealing critically with these issues and achieving practical solutions to operationalize resilience using the framework presented here.



5.

Operationalizing Resilience

5. Operationalizing Resilience

5.1. Introduction

This operational framework draws together the resilience framework presented in Chapter 4, with the theory and practice of strategic planning; systemic inquiry and intervention; and capacity development. It also draws on a decade of the author's field experience seeking to build system resilience through action at multiple levels: household, community, regional (sub-national), national, regional (supranational) and international; through Engineers Without Borders, the Australian Department of Defence, and the CGIAR Climate Change, Agriculture and Food Security Research Program.

This experience contains repeated examples of what, to systems thinkers and development practitioners alike, is a familiar story: a problem is identified (often by an external actor with funding from an external agency), a solution is attempted and, sooner or later, the unintended consequences of the solution become evident. Sometimes the solution fails entirely, sometimes it works (to some degree) but creates other issues; sometimes there are even unanticipated positive consequences. The author of this thesis published a paper about these experiences and their implications for resilience and systems thinking in the journal,The Systemist,(Helfgott, 2008). This chapter draws on these lessons and this paper. The operational framework presented here is based on the acknowledgment that practitioners 'fail more often because [they] solve the wrong problem than because [they] get the wrong solution to the right problem'(Ackoff, 1974). That is, they fail because the development (or systems) practitioner simply does not comprehend the full social complexity of the problem context in which they are working. As Anderson states,'I have yet to see any problem, however complicated, which, when looked at the right way did not become still more complicated'(Anderson, 1969).

In response to this acknowledgement, the operational framework seeks to ensure that the values, knowledge, wisdom, capabilities and resources of affected stakeholders is engaged in the construction of a shared understanding of the problem context and, by way of implication, the articulation of systemically desirable and culturally feasible improvements. It aims to be interpretive, communicative and pluralist in nature, rather than functional, technocratic or monistic. It arose out of a desire to put a stop to interventions that are the impositions of remote technocrats on the needs of others and to seek to minimize unanticipated deleterious effects of intervention.

As such, the framework seeks to address a current deficit in professional competence by providing resilience practitioners with ways of being critically reflective on the key questions that frame resilience; transparently dealing with the value judgments involved in this framing, including what constitutes improvement, for whom and who gets to decide; with pluralism of values, goals and frames amongst different stakeholders and experts;and hopefully also to contribute to increased ability to accept and manage within contexts of uncertainty and complexity without needing to retreat into the competence trap of traditional technocratic modeling approaches and attempts to remove or reduce uncertainty and complexity.

As prominent systems thinker Russell Ackoff noted, "Managers are not confronted with problems that are independent of each other, but with dynamic situations that consist of complex systems of changing problems that interact with each other. I call such situations messes. Problems are abstractions from messes by analysis ... Problems may be solved; messes need to be managed. If we insist on the solution mode, analysis will be relegated to those relatively minor problems which are nearly independent, while messes go inadequately managed" (Ackoff, 1981). Resilience practitioners cannot afford to retreat from these difficult problems to adopt a disconnected position of scientific objectivity, which does not exist in relation to resilience.

Schön talks about the 'real-life swamp' rather than the 'high-ground of technical rationality': 'In the swampy lowland, messy, confusing problems defy technical solution. The irony of this situation is that the problems of the high ground tend to be relatively unimportant to individuals or society at large, however great their technical interest may be, while in the swamp lie the problems of greatest human concern. The practitioner must choose. Shall he remain on high ground where he can solve relatively unimportant problems according to prevailing standards of rigour, or shall he descend to the swamp of important problems and non-rigorous inquiry?' (Schön, 1987).

The author of this thesis was also faced with this choice: to solve relatively unimportant problems in a rigorous manner, and produce a traditional PhD in mathematics or, given what the attempt to develop the mathematics of resilience had revealed (as per the chapters thus far), find ways to make sense of the mess of confusing problems which relate to the resilience of human and natural systems, that often defy satisfactory technical definition let alone solution, work out what the role of formal modelling could even be in such situations and provide methodological contributions to help address the lack of professional competence on these fundamental matters. The choice was clear. The operational framework presented in this chapter is applied both qualitatively and quantitatively in Chapters 6 and 7 respectively.

5.2. What we get from Resilience Theory

Recall from Chapter 4 that, in order for the concept of resilience to be applied meaningfully, resilience of what, to what, from whose perspective and over what time frame must be specified. Where system boundaries are drawn, which factors are included in the analysis, which features of the system are allowed to change, which must be preserved and to what degree, and what is perceived to constitute improvement within those boundaries, completely determines what is interpreted as adaptation, resilience, vulnerability or collapse and so forth.

Figure 5.1. Resilience Framing Cycle.

[In the above diagram, 'time frame' needs to be 2 words]

The example of the Mayan Civilization in Section 4.1 highlights the absolute dependence of classification of resilience or adaptation versus vulnerability or collapse on system boundary judgements, identity and notions of desirability. The interpretation of resilience and adaptation, or vulnerability and collapse, is thus dependent on perspective and values for any system. The type of disturbance is also important – the to what? Systems can be very resilient or adaptable to one type of disturbance but vulnerable to another, and which disturbances are relevant to consider depends on the timeframe under consideration. See Section 4.1 for examples including Mumbai slums, Australian agricultural systems and the Internet. The Australian agricultural and Internet examples were also used to demonstrate that actions taken to increase robustness to one type of disturbance can increase fragility to other types of disturbance, especially unknown and unforeseen disturbances in the future. This raises the issue that adaptation actions taken now, particularly those aimed at building robustness and security, can lead to reduced adaptive capacity in the future. Since we cannot predict, still less control,all of the sources of change that affect systems on which we depend, we should seek to conduct adaptation interventions that build adaptive capacity. Humility in these matters is a necessity.

5.3. What we get from Systems Thinking

There are links between physical, social, economic, political and ecological systems at all scales (Gunderson and Holling, 2002, Grothman and Patt, 2005, Stern, 1992, Mikkelson et al., 2007, Adger and Kelly, 1999, Adger et al., 2005, Ribot, 2009, Midgley, 2000a).These links make the setting of system boundaries, when seeking to understand or to intervene, difficult and often highly contentious. This is crucial, since the way that boundaries are drawn around scope, scale and time frame, which disturbances are considered, and what the notions of desirability or improvement are for whom and by whom, often completely determines the conclusions and recommendations for action.

Due to the interdependence and interconnectedness of social, economic, political, physical and environmental issues at all scales, resilience thinkers face what is known in systems thinking as 'the problem of holism'(Ulrich, 1993). The problem of holism is this: in order to include the entire relevant problem environment in one's definition of a modelling, design or governance issue, it would be necessary to expand our system boundaries until we have included 'the World and God and everything' (ibid), producing an intractable problem which we cannot even think about, let alone model conceptually or mathematically; or we are left with a problem that is incompletely specified because we have left something relevant out of the analysis.

The primary insights of systems theory of relevance here are: 1) that we are forced to make system boundary judgments; they are inevitable since we cannot have a God's eye view of everything in all its interconnectedness and complexity because there are inevitable limits to our understanding (Ulrich, 1983, Midgley, 2000b, Churchman, 1968); 2) that these system boundary judgments are normative and not an objective representation of the structure of reality (ibid). 'It is not the reality "out there" that determines the boundary between the system and the environment, but rather the inquirer's standpoint, the purpose of his mapping effort, his personal preconceptions of the reality to be mapped and the values he associates with it'(Ulrich, 1983).

The system boundary judgments inform the systems models subsequently developed and, therefore, our understanding of that portion of the 'real' world (Churchman, 1968). Moreover, as discussed, these boundary judgments also determine what will be defined as resilience or adaptation versus degradation or collapse.

Accepting that boundary judgments are inevitable, normative and affect our conclusions and recommendations for action about resilience implies that it is a methodological necessity to involve as many diverse stakeholders as possible in the process of framing system resilience and planning resilience interventions(Ulrich, 1983), as well as a moral necessity to involve those whose lives might be affected in whatever intervention we might propose(Churchman, 1968). It is only by being open to exploring the boundaries of issues,through diverse perspectives of different experts and stakeholders,that unanticipated negative sideeffects of intervention can be minimized. This necessitates the use of participatory methods for resilience modelling, planning and decision-making. Furthermore, since we can only ever have a partial view of the relevant problem context, there will always be some unanticipated consequences of any resilience intervention. Accordingly, our approaches must be reflectively assessed and improved through an iterative process of feedback loops. This understanding forms the basis of the reflective, iterative, participatory approach to operationalizing resilience advocated in this thesis.

5.3.1. Critical Systems Heuristics

Critical Systems Heuristics (CSH) is a systemic methodology for handling the issues flagged above: 1) that system boundary judgments are inevitable and everyone makes them, scientists, planners, lay people alike; 2) that these boundary judgments are subjective and shaped by our values; 3) that they determine the knowledge generated and the conclusions and recommendations for action drawn 4) that planners can only ever refer back to the original whole of system judgments to justify the merits of propositions. It is a methodology that supports professional practice through critical employment of the systems idea and a framework for reflective practice. In Ulrich's words,'Critical Heuristics is an effort to provide planners and citizens alike with the heuristic support they need for confronting the problems of practical reason '(Ulrich, 1983).

To make this idea practical, he developed a set of 12 'critical systems heuristics' questions that both planners and ordinary people could use to think through and debate issues. These questions are asked about both what the situation is, and what it ought to be, focusing on four areas: Motivation – why would you want to be planning/intervening in this system in the first place? Control – who should have decision-making power? What should people have some say over, and what shouldn't they have a say over? Knowledge and expertise – what forms of knowledge are necessary and from what sources? Legitimacy – what are the values this is based on? Are you creating an oppressive system, or one that benefits some and hinders others, and if so what should you do about it?

Ulrich's original phrasing of the 12 questions are provided in Appendix A. The language of the original questions is not necessarily easily transferable to field-based development organisations thatare frequently the partners for the implementations of the operational framework described in subsequent chapters. The questions have been rephrased and adapted for the purpose of resilience framing in Section 5.4. Following the methodology proposed by Ulrich, these questions are designed to be employed reflectively by practitioners, and also polemically in dialogical processes involving as many diverse stakeholders as possible.

5.3.2. Systemic Intervention

'Part of the new socially-embedded modeling process was accepting the relevance of multiple rationalities, instead of generating a so-called objective rational policy. We began to realize of course that, if there are different perspectives out there, it's going to matter whether our modeling is meaningful or not to those different perspectives '(Midgley and Richardson, 2007).

Systemic Intervention is a systemic, participatory diagnostic methodology that builds on and incorporates Ulrich's 12 boundary questions. The realization that we can explore different boundary judgements and the values associated with these legitimates the notion of theoretical pluralism: drawing on multiple theories depending on our purposes, which, in this case, include social, economic and environmental dimensions. Different theories assume different boundaries of analysis. For example, the climate analogues model does not directly incorporate social or environmental factors such as the effects of GM on ecosystem services, although the environmental lens we bring does so. If we can decide between a wide range of possible boundaries, we can also draw upon a wide range of theories.

Furthermore, different methodologies and methods make different theoretical assumptions. Therefore, if theoretical pluralism is possible, so is methodological pluralism. This is the theoretical rationale for methodological pluralism, but the most important reason for embracing it is practical. There is no method, as far as the author can see, that can do everything. It is therefore a good idea to draw upon multiple methods for different purposes and to apply multiple different lenses to any situation. This operational framework involves the use of a range of different methodologies from a range of different disciplines and sectors, as will be illustrated in the following chapters.

The key features of Systemic Intervention are:

- Boundary critique using CSH
- Theoretical Pluralism
- Methodological Pluralism
- Dialogical as well as instrumental reason

The logic behind the first three points has already been explained. Dialogical reason quite simply involves social processes of dialogue to generate knowledge and plans in the real world, whereas instrumental reason is the type of reasoning employed in a laboratory where the aim is to separate certain features of a system from confounding factors and the normative content which science obtains when it is applied in the real world (Ulrich, 1987).

5.4. What we get from Development Theory

Over the course of several decades, the development sector has been undergoing a paradigm shift from problem-based approaches, focusing on what is lacking in societies and the provision of external resources, expertise and solutions, to strength-based approaches, focusing on the strengths in societies and building on the capacities that exist, empowering people for their own development from the inside out (Helfgott, 2008). The foundational principle of strength-based approaches is that'although there are both capacities and deficiencies in every community, a capacities-focused approach is more likely to empower people and mobilize citizens to create positive and meaningful and sustainable change from within'(Foster and Mathie, 2001) [1].

Whereas problem-based approaches focus on deficiencies asking, 'Why have you failed?' strength-based approaches focus on capabilities asking, 'What makes success? 'The community looks to the past for where they prospered before and articulate a history of success in their own terms.The process of articulating past achievements and successes builds energy and greater freedom to imagine a desirable future that is less limited by present expectations and negative bias. They then look to the future and envision where they would like to be at the end of the planning horizon. Existing knowledge, skills, tools

[1] For the purpose of description, we use the term, 'community'. However, we recognize that a sense of community cannot be assumed for any particular unit of analysis and, in many cases, groups of people who are geographically co-located do not consider themselves one community; for example, informal settlements in urban areas that are made up of a variety of groups. Therefore, understandings of community is questioned through the process of analysis and not assumed, as this has important implications for identifying decision-makers, who controls access to resources, and through which governance structures resources are distributed.

and resources are systematically uncovered and catalogued; then designs are developed based on mobilization of resources and ownership of plans. The community is engaged in deep processes that honour each participant's capacity for creative self-determination to develop plans and actions to get from where they are now to where they want to go.

The logic of a positive approach is simple: if you focus on the obstacle, you hit the obstacle, whereas if you focus on the way ahead, you miss the obstacle and go in the direction you want. What you look for, where you set your heart, is where you end up.

Using strength-based approaches in practice implies a paradigm shift from the problem-based perspective as 'complex masses of needs and problems' to 'diverse and potent webs of gifts and assets'. Each society hasa unique set of knowledge, skills, tools and resources that can be channeled for development. The role of external intervention is to support local actors in being drivers of change in their own context, through an iterative process of articulating visions, goals and community capacity as they evolve. Two methodologies for strength-based development are drawn upon in the operational methodology: Asset-Based Community Development (ABCD) and Appreciative Inquiry (AI). Each of these will be described in turn.

During the development of this framework the author published a paper covering in more detail the history of development and strength-based approaches, relationships with systems theory and resilience, and a Cambodian case study. This paper, published in the journal of the UK Systems Society, 'The Systemist' is provided in Appendix B(Helfgott, 2008). Some elements of this publication are included in this chapter.

5.4.1. Asset-Based Community Development (ABCD)

ABCD begins by mapping completely the capacity and assets of individuals, local associations and institutions. It is essential that each person's gifts and assets be recognized, even people who have been marginalized within the community. This releases the power of the individual and allows all of those affected to take ownership over the development process (Kretzmann and McKnight, 1993). A similar process is followed with local associations, both formal and informal. Formal associations, such as provincial administration, chief and village elders, religious groups or sporting clubs, can sometimes be easier to identify than informal associations, like youth groups, families or groups of friends. However, identifying informal associations is important to allow for the involvement of all stakeholders, to account for multiple governance structures that exist in heterogeneous communities, and to promote the perception of legitimate processes of an ABCD exercise.

Assets that can be included in an assets map are, for example, social, human, natural, built or financial capital (according to the Sustainable Livelihoods Framework (Twigg 2001)). While widely applied, critics highlight that the asset- and capital-based approach does not capture dynamic processes and power relations which may determine adaptive capacity (Jones et al, 2010). A capital-based approach also does not account for intangible factors such as innovation and flexibility, which determine a system's ability to deal with shocks

(Eriksen and Kelly, 2007). Therefore, asset mapping should also include these considerations (Foster and Mathie, 2001).

The next step is to build relationships among the local assets to facilitate mutually beneficial problem solving within the community. ABCD is a relationship-driven approach. It is viewed as a means of putting the concept of social capital into operation. According to Putnam (Putnam, 1994) the term 'social capital' refers to features of social organization networks, trust, reciprocity and duty that increase both individual and societal capacity for advancement. Social capital is commonly understood by the phrase,'it's not what you know, it's who you know'. According to Ritchey-Vance, lack of assets is '[not] just the lack of material goods. It is also distance from decision-making and a sense of being devalued that manifests itself as apathy, anger and a weakening of the civic culture. The kind of short-term, tangible results that satisfy planners and funders may mask the symptoms of underdevelopment" (Ritchey-Vance, 2002).

Through mapping and linking the assets identified in the ABCD approach, particularly formal and informal organisations and groups, social capital can be identified and mobilized. Mobilization can take different forms, including the convening of groups for strategizing, planning and implementation. Part of ABCD is to ensure that as broad a representative group as possible is convened for the purpose of building a community vision and plan. Finally, ABCD leverages activities, investments and resources from outside the community to support asset-based, locally defined development. Leveraging one form of capital can support the health of another form of capital, such as promoting social capital to secure natural capital. For example, a group of people who employ social capital who work together to clear drains of solid waste to prevent flooding during rainy seasons, in turn, reduce uncollected waste being deposited into rivers and other natural drainage systems, thereby degrading natural capital through pollution.

5.4.2. Appreciative Inquiry (AI)

'Appreciative Inquiry is about the search for the best in people, their organizations and their environments'(Copperrider and Srivastva, 1987). It involves a focused inquiry into what 'gives life and energy to a system' from the perspective of stakeholders(Hall and Hammond, 1998). It is based on the theory that positive change comes from appreciating what exists and focusing on the successes of the past. AI involves asking questions that 'strengthen a system's capacity to apprehend, anticipate and heighten positive potential'(Copperrider and Whitney, 1999). Some approaches to AI involve community members themselves gathering all the information through interviews, and, in others, the community is facilitated to share this information among members of the community group through storytelling and focus groups. The broadest possible group is then convened and facilitated (internally or externally) to develop its own strategies for development, based on the findings from their shared journey to their positive past.

Appreciative Inquiry is a very flexible approach. One common model for its use is the 5D cycle: Define, Discover, Dream, Design, and Deliver. In the Define stage, the participants decide on an area of interest. In the Discovery phase, participants are encouraged to gather stories and insights broadly about past and present successes and achievements;

knowledge, skills, resources, innovations, strengths, opportunities, wisdom and insights into what has made their community successful in the past. Once the 'positive and life-giving energies of the community' have been Discovered, the positive outlook built by the experience puts the community in a more open frame of mind to Dream about what could be possible for their future and what they really want, unfettered by negative expectations or biases. After all, if we don't know what we really want, we risk creating something else, potentially something no-one wants. After imagining'what could be', the community must Design a plan from this brainstorming of how to achieve the desired future possibilities, using past successes and the capabilities that have been identified and mobilized through the process. The final stage of the model, Deliver, is going and doing it. This stage involves constant monitoring and evaluating of the effects of our actions, adjusting them as we go, to make the dream a long-term reality.

These approaches fit seamlessly with the insights from resilience, adaptation and systems thinking, which tell us that we need to involve as diverse an array of stakeholders as possible in the process of defining the purpose, scope, timeframe, measures of success, and so forth, of any proposed intervention in order to adapt to climate change and minimize unanticipated negative side effects. Since it is only ever possible to have a partial view there will always be unanticipated consequences of any intervention. Therefore, local ownership is crucial for success and sustainability, so that those involveddo not lose faith in themselves, the intervention or not know what to do as circumstances change.

5.5. What we get from Strategic Planning

Any type of planning requires knowing where you want to go, where you are now, the context you will have to act within and the options and tools available to get there, as shown in Figure 5.2. This may seem blatantly obvious.Yet, especially in academic contexts, often little to no time is spent discovering and articulating the vision or goals for desirable outcomes or states; this is skipped over or taken for granted and immediate focus is directed to the details and challenges of modeling or implementation(Meadows, 1994). However, without an articulated vision of where we want to go, it is very difficult to plan to get there and we may end up planning and achieving something we don't want. Accordingly visioning is an important part of the operational framework. Equally, this stage articulates what is desirable and what is undesirable, and to whom.

The term shadow scenario is used to describe the set of assumptions about the way the world works and the way the future will be (often a continuation or worsening of current trends). The shadow scenario shapes the actions they consider appropriate and feasible, and shape what they believe is possible. These assumptions can limit the options and tools considered and also blind decision-makers to consideration of the uncertainties in the 'context we have to navigate within' part of Figure 5.2 thereby reducing resilience and adaptive capacity.

There is often a need to clarify what is going on now in a multi-stakeholder process, since everyone has different knowledge and perspectives of the situation.

This operational framework involves clear articulation, and critical processes to reflect on; where we want to go, where we are now, the context we have to navigate, and the options available for achieving desired futures.

Figure5.2. Strategic Planning Framework

5.6. Integrated Operational Framework

As described above, resilience and adaptation theory tell us that to meaningfully apply the concept of adaptation in practice we must ask: adaptation of what, to what, from whose perspective (as in what/whose measure of improvement will be adopted) and over what time frame? Methodologically, answering these questions is done recursively as shown in the diagram in Figure 5.1.

Critical Systems Heuristics provides a systematic methodology for characterizing the system of interest and making all related normative content explicit. It allows for participatory determination the 'of what, to what, from whose perspective and over what time frame', which, in fact, needs to be unpacked in even further detail to address explicitly questions of motivation, power, knowledge and control, as can be seen below. Adapting CSH to resilience gives us:

1. **Resilience of what?** What is included within the scope of the system of interest to be focused on? What are the boundaries of the system of interest – what is/ought to be included in analysis, planning and action and what is outside the scope? (Which social, technical, economic, political, ecological factors should be included/excluded?)
2. **Resilience to what?** Which stressors/disturbances are being considered? What are the drivers of change and what are their relative priorities/interactions?
3. **Resilience from whose perspective?** What are the key features of the system that need to be preserved, what can change and what constitutes desirable versus undesirable change, to whom?
4. Who is/should benefit from the resilience program? That is, whose interests should be served – which human actors, non-human species and so forth?
5. What is/ought to be the purpose of the resilience program? That is, what should be the consequences?

6. What is/ought to be the measure of success of the resilience program? How can we determine that the consequences taken together constitute an improvement?

7. **What is the time frame** over which adaptation activities will be planned, implemented and evaluated?

8. Who is/ought to be the decision-maker at which stages in the design, implementation and evaluation process?

9. Where do/should resources come from and who should control them? Through what processes should the resources be distributed?

10. What forms of knowledge and expertise (scientific/local/traditional/etc.) are/should be sought and incorporated at which stage in the process?

11. What or who is/ought to be assumed to be the guarantor of success? That is, where do those involved seek some guarantee that improvement will be achieved – for example, consensus among experts, the involvement of stakeholders, mathematical models etc.?

12. Who is/ought to be the witness to the interests of those affected but not involved in planning, decision-making or implementation? That is, who should be treated as a legitimate stakeholder, and who argues (should argue) the case of those stakeholders who cannot speak for themselves, including future generations and non-human nature?

13. What secures the emancipation of marginalized groups from the premises and promises of those involved in planning and decision-making?

According to Ulrich, these questions completely frame the system and the design. There are likely to be differences in opinion on the answers to these questions between stakeholders and negotiation will need to occur. These questions are designed to be applied reflectively by the team of researchers involved in characterizing and managing resilience and also polemically in dialogical processes involving both involved planners and affected citizens. The methods, described in this chapter and the following ones, for getting at the answers to these questions are participatory dialogical processes. Note that the questions about power, legitimacy, knowledge and expertise and who should benefit directly allow for a systematic examination of the social, cultural and gender-specific dimensions of resilience.

Applying the principles of Systemic Intervention, in order to address these questions, requires that the operational framework adopts theoretical and methodological pluralism. This means using multiple methods and tools from multiple theoretical backgrounds to seek answers to the questions above. The framework encourages resilience research to be conducted in interdisciplinary teams so that lenses from different disciplinary backgrounds (which tend to pick out different features/have different appreciative systems) can be applied to the same topic. The framework encourages the use of multiple participatory methods with the same group and the same methods with multiple groups to triangulate perspectives.

In structuring the application of specific methods, we draw on Appreciative Inquiry – looking to the past to build on existing knowledge and expertise and see where things have been done well (this includes oral histories and looking at how things have changed), looking to the future to see where we want to go (mapping the values, visions and aspirations of the community to obtain a community-based measure of improvement), developing a plan for how to get from where we are now to where we want to go. Illustrative examples are provided in the following sections and chapters.

5.6.1. Pluralism

The term pluralism implies that diversity exists, and that there are multiple of whatever it is the term is being applied to, be it perspectives, theories, methods, disciplines and so on. In philosophy, it is often used in opposition to monism– to say that there is not only one way of understanding the world or of seeking and organizing knowledge about it. It is associated with pragmatism and contextualism.

There are multiple ways that practitioners deal with pluralism. Drawing on the work of Mike Jackson and Wendy Gregory these can be loosely summarized as (Gregory, 1992, Jackson, 1987):

- Isolationist: An isolationist is someone who believes their theory and methods are sufficient and others are irrelevant.
- Imperialist: An imperialist is someone who believes their theory and methods are superior but is willing to draw from others where they see that others support or strengthen their own.
- Complementarist: A complementarist is someone who believes different theories and methods are suitable for different problem contexts.
- Discordant pluralism: An advocate of discordant pluralism acknowledges that often different theoretical perspectives are discordant, and cannot be resolved into a single overarching theory without distortion and loss of nuanced information that is contained in each perspective. Each perspective should be appreciated for what it is and the tensions between them are keys to deeper understanding, as they promote continued debate and communication between different perspectives.

Gregory showed that complementarism collapses into its own form of imperialism through the meta-theory that specifies when to apply different theories and methods. The one meta-theory that subsumes all others itself relies on a priori categorization of problem context. Gregory is therefore skeptical of one paradigm being subsumed within another and instead calls for discordant pluralism (Gregory, 1996b).

Matthews argues that 'discord is perhaps the most fundamental characteristic of "true" pluralism; a pluralism devoid of any totalizing attempt to reduce or control the diversity of viewpoints offered'(Matthews, 2004). Therefore, rather than minimizing tensions, discordant pluralism aims to promote communication between 'discordant' theoretical perspectives with the aim of coming to a deeper understanding than that achievable by attempting to reconcile or compartmentalize them as in complementarity. It accepts the local, contingent and historically situated nature of any pluralistic understanding of the different approaches.

Midgley argued that '[Gregory] advances our thinking by examining the nature of communication between people based in different paradigms. Every time one person listens to another whose thinking is based in another paradigm, he or she can only interpret what they are saying through his or her own terms of reference ... care is needed not to be either dismissive or to think that full understanding has been achieved. If care is taken to appreciate the other, in the knowledge that full understanding in the other's own terms is impossible, then one's own learning ... can be enhanced'(Midgley, 2000a). He calls this attitude'a critical appreciation of alien paradigms' and suggests that it helps shift the emphasis of interaction from knowing to learning and creates more space for openness and preparedness to listen to alternative positions when we encounter them. Gregory also noted that our understanding is always contextual and dynamically changing as we learn more: 'any appreciation of another's position will be subtly altered on each occasion that it is considered'(Gregory, 1996a).

All of the above is captured in her definition of discordant pluralism as: 'a shifting nodal point in which different, competing and conflicting perspectives may intersect in a tension which lasts only a critical moment'(Gregory, 1996b). The operational framework for resilience put forward in this thesis requires practitioners adopt the practice of 'critical appreciation of alien paradigms' when working with diverse stakeholders and experts and when seeking to understand and manage issues that cross disciplines, sectors and social worlds. This operational framework is based in acceptance of the notion that the knowledge generated by different disciplines sectors and social worlds is sometimes discordant or conflicting and that we can achieve a greater understanding by improving dialogue rather than smoothing over tensions or creating a totalizing framework.

Following the advice of White and Taket, this operational framework requires pluralism in each of the following (White and Taket, 1994):

1. **The facilitation process:** For any participatory planning or analysis, pluralism in the facilitation process is advanced by a strategic reduction in the expert's authority. White and Taket suggest that 'a post-modern expert would be more of an interpreter, and would recognize any project of interpretation as something that can be carried out collaboratively'(White and Taket, 1994). White and Taket hope to subvert the traditional understanding of a practitioner as holding the privileged position of 'expert'. They state, 'It is a mistake to accept the expert as having the final word as to the meaning of the client's problems'.

2. **The modes of representation employed:** Pluralism in the modes of representation employed is advanced by disputing the claims to objectivity suggested by certain types of representation, namely those that are furnished with raw data and come unencumbered with subjective value judgments. White and Taket (White and Taket, 1997) suggest that practitioners always play a role in 'constructing' that which they later claim to have discovered. As such, the representation of any given system is contingent on judgments about the appropriate boundaries of the system, a position we have already explored in our review of Ulrich and Churchman. Accordingly, White and Taket (White and Taket, 1994) suggest that systems practitioners need to develop modes of representation that can be produced in conjunction with participants and are, therefore, open to interrogation by them such that they can experience ownership and participation in the justification and

decision-making process.

3. **The use of specific methods/techniques:** Instead of directing practitioners to specific systems or scientific approaches for specific problem contexts, Taket and White suggest guidelines for critical action. These guidelines encourage practitioners to creatively design their own methods to fit each situation. These guidelines strikingly capture the essence of the strength-based approach to capacity building, for example (italics represent quoted guidelines taken from(White and Taket, 1997)

   'Withdraw allegiance from the old categories of the negative, which Western thought has so long held sacred as a form of power and an access to reality. Prefer what is positive and multiple: difference over uniformity; flows over unities; mobile arrangements over static systems.' This is itself the fundamental tenet of strength-based approaches as opposed to problem-based approaches.

   *'Do not think that one has to be sad in order to be militant, even though the thing one is fighting is abominable. It is the connection of desire to reality (and not its retreat into forms of representation) that possesses revolutionary force. '*This indicates that it is possible to have fun, to enjoy the energy generating processes of building on strengths and successes with gratitude and appreciation for what exists and achieve real, sustainable positive change.

   'It is important to recognize the co-responsible nature of the encounter, with the co- participation of the different parties involved.'

   'Aim to achieve "skill" transfer (both ways) and empowerment of all involved.'

   'Recognize difference and work with it (difference as generator of multiple possibilities, acting to increase choice rather than constraining it) but work non-hierarchically.'

   'Aim to break down stereotypes of the "expert", the "professional" and reduce the perceived distance between practitioner and client.'

   'Aim for flexibility, be ready to adapt and work in different ways at different times, willing to depart from plans and from detailed methodologies.'

4. **The nature of the client:** Pluralism in the nature of the client is advanced by acknowledging and respecting the views of a wide range of stakeholders in the intervention. The presence of different views of the problem/system(s) of interest may require the practitioner to work with more than one rationality simultaneously. Different stakeholders have appreciative systems, informed by different boundary judgments, goals or values, none of which is more legitimate than others.

   In keeping with these principles, the operational framework presented here does not specify which particular methods must be used to answer the key questions which frame resilience and determine its characterization and/or measurement and suggest approaches to building resilience. Practitioners are encouraged to work in interdisciplinary/ inter-sectoral groups, together with stakeholders to co-design appropriate methodologies for joint inquiry, analysis, intervention and monitoring and evaluation.

This thesis gives examples of some specific instantiations of the operational framework presented here in practice. It is highlighted that the framework is transferable and any sets of appropriate methods can be used to identify resilience 'of what, to what, from whose perspective, over what time frame', including what constitutes desirable change to whom and all of the relevant questions that go into understanding and modeling resilience as covered above. Practitioners should work with stakeholders to design appropriate methods to address the key issues in framing and planning for resilience, as described here.The particular instantiations of the operational framework covered in this thesis are as follows: Section 5.8in this chapter covers a parsimonious participatory methodology for operationalizing resilience within the course of a 3-day diagnostic, prioritization and planning workshop. Chapter 6 gives a case study of the operational framework including the 3-day workshop, in Nepal. Chapter 7 illustrates the operational framework and applies the mathematical framework for measuring resilience. Chapter 8 applies the operational framework to resilience research program design.

5.7. SIRA Diagnostic, Prioritization and Planning Workshop

5.7.1. Introduction

This section describes one particular instantiation of the operational framework: the specific methodology for the 3-day Systemic Integrated Resilience and Adaptation (SIRA) Diagnostic, Prioritization and Planning Workshop. A detailed manual for this workshop has been developed and is available online through www.ccafs.cgiar.org as Working Paper number 76(Helfgott et al., 2014). This workshop was entirely designed by the author of this thesis to implement the operational framework for resilience specified here and she has successfully implemented it repeatedly in Kenya, Senegal, Ghana, Nepal, Viet Nam and Laos; has been replicated by the United Nations Environment Program World Conservation Monitoring Centre (UNEP-WCMC) for its resilience of Marine Protected Areas program in West Africa(UNEP-WCMC, 2014); and is used by the CGIAR Climate Change Agriculture and Food Security Program for resilience and adaptation diagnoses and planning in East Africa, West Africa, South Asia, South East Asia and Latin America.

The 3-day workshop implements the operational framework for resilience presented in this chapter. Particular attention has been paid to the ordering of activities within the adaptation planning process to take into account cognitive pre-framing of participants in order to minimize the researcher/development worker effect and maximize community empowerment. The ordering of activities draws on strength-based community capacity development approaches and, in particular, on Appreciative Inquiry (AI).

The most common model of AI is the 5D cycle: Define, Discover, Dream, Design, and Deliver. In the Define stage, the participants decide on the focal system (of what), time frame (over what time frame) and relevant challenges (to what). This is achieved through the following activities:

- What's Important?
- Challenges Clustering
- Causal Mapping
- Challenges Ranking

In the Discovery phase, participants are encouraged to gather stories and insights broadly about capacities, achievements, assets, unexplored potentials, innovations, strengths, opportunities, benchmarks, values, traditions, competencies, stories, expressions of wisdom and insights into what has made their community successful in the past. This identifies existing strategies and tools for coping with challenges that can be built upon. Articulating successes builds energy for the following activities. This is achieved through the following activities:

- Response Clustering and Story Circles
- Spotlighting Stories of Success

Once the positive and life-giving energies of the community have been Discovered, the group comes together to Dream about how these past experiences can apply to the community's future. In the energy of the moment, they imagine 'what could be' for the community. This is achieved through three distinct visioning exercises designed to capture physical, environmental, social, psychological, economic and political aspects of desired futures:

- Collages
- Future Village Map
- Visualization

The community prioritises aspects of these desired futures for detailed planning. This is achieved in the following activity:

- Prioritization for Adaptation Planning

Then, the community must Design a plan of how to achieve the desired future goals using past successes, as well as the present capabilities, assets and resources. These capabilities, assets and resources are identified in detail in through the following activities:

- Resource Mapping
- Formal and Informal Organizations and Institutions
- Sustainable Livelihoods Framework
- Individual Strength Mapping: Community Valentines

The Design phase is fully implemented by backcasting from future goals to present assets, resources and capacities, providing a step-by-step plan that can be followed from the present moment, embodying the principle that 'wherever you are, you can always take a step'. Supporting organizations that will assist the community to follow through with their plans and that can add information in the detailed planning phase can be present for this stage. This is achieved in the following activities:

- Linking with Support Organizations
- Backcasting

After this workshop has been completed, scenario development and testing can be implemented. Development of scenarios for alternative plausible futures builds capacity for decision-making under uncertainty and change, and it provides plans that are robust across a broad range of plausible futures. This is achieved through the following activities:

- Scenario Development
- Scenario Testing

The final stage of the model, Deliver, is going and doing it. This stage takes the planning of the workshop (and potential scenario work) and puts it into practice, with appropriate support and constant monitoring and evaluating of the effects of our actions, adjusting them as we go, to make the dream a long-term reality. Note that adaptation, like any change process, takes time. The community will require ongoing support and follow-up activities from local support institutions for quite some time beyond the scope of the initial project intervention.

This chapter elucidates sets of specific tools for achieving these objectives.However, within the framework presented here, the tools are flexible and many be tailored or substituted with other approaches in each context, if need be, to emphasise specific resilienceissues. The overarching framework for analysis and capacity building and the order of activities remain relevant across contexts and any groups of stakeholders. The result is an empowering approach that builds on existing knowledge, skills and resources, to develop and implement appropriate adaptation pathways that align with local visions and values, and balance human development with environmental management objectives.

5.7.2. Pre-workshop

Care should be taken to identify all existing forms of social differentiation within the community (for example, gender, caste, ethnicity, disability, age, sector). This can be done through consultation with local partners who have an ongoing relationship and knowledge of the community, village leaders and a small number of interviews with general members of the community. Participants should be sampled in representative proportions from all groups.

This workshop is designed to fit within 3 days of 7 hours each (for example, 10:00-17:00 with a 1-hour lunch break and two 30-minute tea breaks). However, while the order of the activities should be maintained as they build upon each other, the workshop program can be spread over any number of consecutive days (for example, 4 days of 3-4 hours in length). Timing of the workshop should be based on the availability of participants in order to maximize attendance and consistency.

Within this framework, the order of the phases is important and should be maintained. However, specific activities can be substituted and/or tailored in consultation with local facilitators and experts in order to be appropriate for local conditions. Tailoring of the activities should consider literacy, numeracy, ability of different social groups to express themselves openly in front of one another, etc.

When holding the workshop at the community level, it is preferable to hold the workshop within the village itself (rather than choosing an external venue). Experience indicates that participants are significantly more at ease and more likely to fully engage with the process, as well as the data collected being of better quality, if the workshop takes place on their own territory.

This workshop has traditionally been conducted with 60-80 participants working in 3 to 4 breakout groups, with up to 20 people in each, with the exception of 1 or 2 activities that are done with the larger group. The number of facilitators required is one per breakout group. Two facilitators per group are better than one, as one observes and prompts the facilitator who is most active, and they can switch to give each other a rest.

This workshop can certainly be done with less people. The less people the more careful you need to be about how representative your sample is. The minimum group size is 3-4. There need to be enough people to stimulate discussion. The maximum group size is roughly 20, and a group above 15 requires a skilled facilitator to manage.

Care should be taken in the composition of groups to ensure that participants will be able to express themselves freely. Each community has different norms of representation and decision-making, so group structure needs to be determined on a case-by-case basis in consultation with local partners and key informants in the community.

Examples of groups in which sensitivity may exist:

- Women
- Young people
- Minority ethnic groups
- Disability and disease (e.g. HIV)

All of the activities in this workshop are participatory exercises.

5.7.3. Diagnostic, Prioritisation and Planning Workshop

The Workshop fits well within a 3-day program in which the first day achieves scoping of the relevant system, diagnosis and prioritization of vulnerabilities and adaptation challenges. This is followed by the identification of existing response strategies and tools, opportunities and barriers to adaptation. Accordingly, Day 1 maps onto the 'of what, to what' aspects of resilience framing and the 'Define' and 'Discover' phases of AI.

The second day begins with developing shared visions of the future and prioritizing goals for planning and action, and ends with detailed mapping of all the assets, resources and capacities available with which to achieve these goals. Day 2 contributes to the 'from whose perspective and over what timeframe' aspects of resilience framing by defining what constitutes desirable improvement –to whom, over what timeframe for the future. The activities map onto the 'Dream' and 'Design' phases of AI.

The third day is dedicated to backcasting step-by-step plans that build on present strengths to achieve future goals. This includes identifying linkages with appropriate support institutions and assigning responsibilities for tasks to take the plans forward. Day 3 is action research with respect to resilience. Having framed resilience, we begin to explore how to build resilience in practice through an active planning intervention, building on local strengths and capacities to achieve locally defined measures of success and improvement in the face of change. Day 3 maps on to the 'Design' phase of AI and overlaps with 'Do', since it is an active, participatory planning process. 'Do' continues after the workshop since the participants must then implement their plans.

This workshop draws together theory and practice in a unique way and provides a parsimonious practical methodology for addressing resilience in an empowering and strength-based manner. It fills a gap in practice and, as such, has been adopted by government agencies, international institutions, research organizations and field-based organizations around the world. As mentioned in Section 5.7.1, this workshop has been successfully implemented and replicated by local partner organizations in Kenya, Senegal, Ghana, Nepal, Viet Nam and Laos; has been adopted by the United Nations Environment Program World Conservation Monitoring Centre (UNEP-WCMC) for its resilience of Marine Protected Areas program in West Africa (UNEP-WCMC, 2014); and is used by the CGIAR Climate Change Agriculture and Food Security Program for resilience and adaptation diagnoses and planning in East Africa, West Africa, South Asia, South East Asia and Latin America. The Lawra District Assembly in Ghana has adopted the workshop in its district-level planning processes.

5.7.3.1. Day 1: Framing Adaptation: of what, to what, on whose terms?

5.7.3.1.1 Setting scope in terms of local values

WHAT'S IMPORTANT EXERCISE

BRIEF DESCRIPTION

This activity is conducted with all participants together, often 60-80 people at once. The purpose is to construct a broad representation of what is important and relevant to the community as a whole. This gives conceptual scope to the relevant system for analysis. The What's Important Exercise is able to capture tangible aspects of community life, such as water, crop productivity and schools as well asless tangible aspects, such as community cohesion, a feeling of safety, spiritual identity – all of which may prove relevant for resilience or adaptation planning but many of which are unlikely to be voiced directly in purely adaptation planning-focused activities.

SPECIFIC OBJECTIVES

This exercise kicks off the workshop in a spirit of openness and inclusivity, since everyone's interests are included and nothing is too small or too personal to make it onto the board. It sets the tone of the workshop as being completely driven by community priorities and also functions as an icebreaker. It allows researchers and practitioners, who do not have a long-term relationship and knowledge of a community, to rapidly obtain a broad understanding of local values and priorities beyond adaptation alone. These values and priorities have a practical impact on prioritization of resources for resilience or adaptation initiatives (it tells you what else is going on that is a prioritycompeting with the project objectives) and can impact on effective and sustainable implementation of an initiatives.

EXPECTED OUTCOMES

- Shared understanding of what is important and relevant to the community as a whole, weighted in terms of size of clusters.
- Provides an understanding of local values and priorities including, but not limited to, adaptation.
- Conceptual boundaries of the system are explored.
- Potential conflicts and synergies with adaptation planning can be identified.

Figure 5.4. What's Important Exercise.

OUTPUT

The final output of this exercise is a visual representation of what is important to the community as a whole, with visual weighting of different issues in terms of cluster sizes, as well as a synthesis of the discussions on values and issues.

5.7.3.1.2 "Resilience to What? For Whom and By Whom?"

This stage of the workshop is conducted in multiple phases. During each phase of the activity, the participants are divided into 3 breakout groups according to the dominant form of social differentiation (for example, one group female, one group male and the third group mixed). In the first phase, the participants explore the dimensions of vulnerability and exposure, and the key resilience and adaptation challenges they are facing, which characterize 'to what'. The next stage brings together the challenges and disturbances identified in these breakout groups, and maps out their interrelationships and how they are mediated by various factors, such as ecosystem services provided by the surrounding area. While the dimensions of vulnerability, exposure and challenge need to be explored, to avoid a negative focus this activity is grouped together with the responses exercise, simultaneously stimulating people to think of themselves as survivors.

CHALLENGES BRAINSTORMING AND CLUSTERING

BRIEF DESCRIPTION

This activity is conducted in breakout groups of 10-15 people or less. The purpose of the exercise is to gain an understanding of the key vulnerabilities and adaptation challenges facing a community in their own terms. Participants brainstorm and cluster vulnerabilities and challenges into key themes. This activity contextualizes the 'to what' the community is being resilient, and provides an understanding of potential barriers to resilience or adaptation which must be overcome.

SPECIFIC OBJECTIVES

This activity represents one key step in the practical framing of resilience in terms of 'of what, to what, from whose perspective and over what time frame'. It provides the elements of 'to what' of adaptation planning, which is used for subsequent systems analyses, such as the following step of causal mapping between these elements and mediating factors in the community, and prioritization of key vulnerabilities and adaptation challenges.

EXPECTED OUTCOMES

This activity provides input to the causal mapping activity, which explores interrelationships between factors that underpin vulnerability, exposure, coping and adaptive capacity. Further, these activities both provide the basis for exploring response strategies (past, present and potential) during subsequent activities.

CAUSAL MAPPING

BRIEF DESCRIPTION

This activity is conducted in breakout groups of 10-15 people or less. Each group does the same activity. The purpose of the exercise is to conduct a systemic analysis of the relationships between key challenges and any other mediating factors. The cluster headings from the previous activity are written on cards that can be easily moved around on the activity sheet. Facilitated discussion takes place around the relationships between these challenges, and participants are instructed to draw arrows representing casual relationships between these elements. Any extra factors identified through this analysis that mediate causal relationships can be added to cards and included.

SPECIFIC OBJECTIVES

This activity develops capacity for systemic analysis within the community. It provides an understanding and visual representation of how the system functions from the perspective of participants. It highlights the interrelationships between challenges and suggests entry points for transformative change. It also elucidates potential barriers to adaptation and issues that will need to be addressed in an integrated manner in order for sustainable adaptation to be achieved. It pre-frames the subsequent ranking activity, since understanding which factors underpin others often changes the subjective prioritization of vulnerabilities and challenges.

EXPECTED OUTCOMES

- Knowledge sharing within the community producing an enhanced understanding of the interrelationships between key vulnerabilities, challenges and contextual factors.
- Understanding which factors underpin each other may lead to a reassessment of the relative priority of different issues.
- A visual representation of the interrelationships between key vulnerabilities, challenges and contextual factors.
- Informing the subsequent vulnerability and adaptation challenge prioritization activity.

OUTPUT

The activity produces a causal map, showing the interrelationships between key vulnerabilities and adaptation challenges as well as contextual mediating factors from the perspective of the community. A synthesis of discussion around key causal loops and relationships is also recorded.

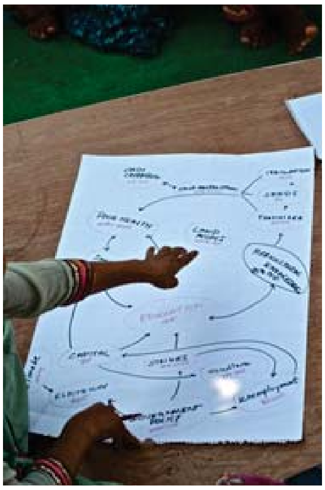


Figure 5.5. Causal Mapping Activity.

CHALLENGES RANKING

BRIEF DESCRIPTION

This activity is conducted within each breakout group (10-15 people or less per group) as the specific challenges may differ between groups. Participants are given 10 stickers per person. Bearing in mind what they have learned from the causal mapping, they are asked to rank challenges by allocating their stickers proportionally to challenges of their choice.

SPECIFIC OBJECTIVES

This activity provides an understanding of the relative priority of various vulnerabilities and adaptation challenges to the community and sets priorities for further planning. Structuring breakout groups according to different forms of social differentiation, such as gender (for example, a group composed entirely of women, a group composed entirely of men and a mixed group) is useful in order to record the relative priority of different issues to different social groups.

EXPECTED OUTCOMES

- Prioritization of challenges in context and according to local experience and values.
- Relative priorities of different social groups are captured.

OUTPUT

This activity produces a ranked list of resilience and adaptation priorities for each social group conducting the analysis, as well as an aggregated list of priorities for the community as a whole.

RESPONSE CLUSTERING

BRIEF DESCRIPTION

This activity is conducted in breakout groups of 10-15 people or less. Using the causal map and the challenges clustering as intermediary objects (an object used to stimulate discussion and focus thinking), participants are asked to brainstorm all past, present and potential future responses to these challenges. Once again, the exercise is very open and participants are encouraged to write down anything at all which they can think of, whether it be something they have done in the past, do regularly, have seen but never tried, have heard of, or simply something they can imagine might be possible. Responses are not clustered according to the challenge they may have been evoked in response to, since individual responses may have consequences which address more than one challenge and clustering by challenge can be confusing for that reason. Instead, the responses are clustered into themes, organized by the type of response involved; for example, infrastructure, institutional support, community organizing and so forth.

SPECIFIC OBJECTIVES

The purpose of the exercise is to elicit all community-endorsed past, present and potential future responses to the vulnerabilities and challenges identified in the previous stages of the activity. In this way, it is possible to map existing coping and response strategies and tools. This exercise will form the basis of the story circles that comprise the next activity.

Note that, in this step, it is only possible for participants to think of things within their sphere of experience and imagination. It is nevertheless very important to map and build on this; however, there is room for capacity development in terms of options during the backcasting phase of the workshop when supporting agencies will be present and may be able to suggest alternative approaches and solutions.

EXPECTED OUTCOMES

- Comprehensive mapping of community-endorsed past, present and potential future response strategies and tools, including resistance, recovery and adaptation.
- Knowledge sharing between participants about different types of response.
- Provides the basis for the narrative event ecology/story circles that comprise the following phase of the activity.

OUTPUT

This activity produces a visual representation of community-endorsed past, present and potential future adaptation response strategies and tools, weighted by the size of clusters.

RESPONSE STORIES

BRIEF DESCRIPTION

This activity is conducted in the same breakout groups as the previous response clustering exercise. Using the response clustering as an intermediary object, participants are asked to share stories about a time they tried any of the responses on the sheet, why and what happened. These stories are shared in a circle for some time. Following this, participants asked if there are any responses on here that they would have liked to have tried but didn't. In this case, participants are asked to share stories about why they didn't try certain things and what they did instead. Finally participants are asked if there are any activities they would like to undertake in the future and to tell stories about the opportunities or barriers to trying new things. During the activity, positive responses and coping strategies are spotlighted and celebrated, building the community's perception of itself as made of survivors, successful in coping with diverse situations. This sense is very important for the visioning exercise that takes place on the following day.

People tell stories naturally and tend to remember stories more easily than they remember facts. Furthermore, stories deliver information with an illustrative context and a time stamp, which facilitates interpretation of the response strategies in context. Also, stories beget more stories and, once a story circle gets going, it provides the basis for very fruitful discussions.

SPECIFIC OBJECTIVES

- Situate response strategies and tools captured during the response clustering exercise in local context.
- Stories deliver information with an illustrative context and a time stamp.

- Storytelling facilitates community capacity development through learning, change and evaluation.
- Stories provide a 'rich picture' of what is going on the community and often carry messages about issues that are un-discussable.
- Elucidate social, cultural, physical, economic, political and environmental opportunities and barriers to adaptation.
- Build positive community self-perception of resilience and survival through spotlighting and celebrating positive stories, building agency and energy for the following activities.

Start with an image-building phrase
'Think about…'
'Imagine…'
'If…'
'Consider…'
For example, 'Think about a time when you experienced flooding.'

Add an additional sentence or two to enhance the image:
'This might have been in your own home or in your farm.'

Use emotive words, as memories are tied to emotions and evoking particular emotions helps participants to recall past events. Some examples of emotive words are:
Frustrated
Elated
Angry
Exhausted
Awed
Timid
Hopeful

Then add the open-ended question with the emotive words:
'When have you been annoyed, ecstatic or just perhaps surprised by the way your local government handled the flooding?'

Box 1. Crafting The Right Questions: Guidance On How To Elicit Stories Rather Than Opinions

OUTPUT

A collection of narratives that create a "rich picture" of the status of adaptation and adaptive capacity within the community, and identify and characterize barriers and opportunities to adaptation and resilience.

Figure 5.6. Response story circle.

5.7.3.2. Day 2: Where we want to go? Where we are now?

5.7.3.2.1 Where we want to go: Shared community visioning

During this stage, each breakout group conducts one of the three activities listed below. If there are more than three breakout groups, more than one group can repeat an activity or other forms of visioning can be adopted. Within the scope of this manual, we cover three approaches as these work comprehensively together. All groups return together to report back and to vote on the aspects of the future to be prioritized for planning activities. This process is covered in 'Resilience Prioritization' below.

Visioning must not be limited by perceptions of current trends or limitations. The purpose of the visioning exercise is to clarify local visions and aspirations for a desirable future and not to capture their current, potentially negative expectations of 'all they could hope for' or where they think things are going. This is about dreams and not about predictions. Quite simply, 'if we do not know where we want to go, there is little chance we can get there'. It is essential to have an unfettered characterization of desirability to ensure plans are not facilitated that enact an undesirable future simply because participants were too frightened to dare to dream about what they really want. Visioning must take people out of their normal sphere of thinking and into the realm of imagination and possibility.

COLLAGES

BRIEF DESCRIPTION

This activity can be conducted in a breakout group of up to 20 people. It is a very flexible and free-flowing activity that is rich in meaning and highly inclusive. Participants are provided with a stack of newspapers and magazines, a set of scissors each and enough glue to share. Everybody is asked individually to cut out pictures of anything that represents some aspect of their desired future. All participants create a collage of everyone's images, overall creating a visual representation of local visions, aspirations and values for the future. The group will then report back to the entire workshop the meaning and the story of the image they have created. The group will prioritize the top 3 or 4 aspects of this future they want to be carried forward for detailed planning activities in the course of this workshop.

SPECIFIC OBJECTIVES

- Create a colourful and inspiring visual representation of a shared vision for a desirable future for the community, incorporating practical physical dimensions, lifestyle characteristics, personal development and so forth.
- Prioritise 3-4 aspects of this desired vision to be carried forward for detailed planning activities in the rest of the workshop.

Figure 5.7. Collages Activity.

OUTPUT

This activity produces a collage depicting a visual representation of a composite desirable vision of the future for the community.

Figure 5.8. Collages Output.

FUTURE VILLAGE MAP

BRIEF DESCRIPTION

This activity can be conducted in breakout groups of 10-20 participants. Participants are facilitated to draw a map detailing how they would like their village to look in the future. This captures the physical details of the village including schools, health care, markets, industry, agriculture, housing, electricity, water storage and distribution, sanitation and so forth. This is essentially an exercise in urban planning. It is well worth the effort. After drawing such a map, the community can really see how their village could look. Accordingly, they find it much easier to imagine that happening, which is the first crucial step towards making it happen. Plans and actions take on a much more focused and motivated sense after activities such as this.

SPECIFIC OBJECTIVES

The purpose of this exercise is to produce a map of the 'future village' (potentially including some relevant aspects of the surroundings) encompassing the community's values and aspirations. The elements on the map illustrate the goods, services, aesthetic and lifestyle considerations that the community would like to provide through its physical landscape. For example, in places where community cohesion is an aspiration, 'future maps' often include a community centre and other places of gathering for various community-based activities. This activity also contributes to understanding the scope of the system under consideration.

OUTPUT

The outputs of this activity are the map of the future village, the list of elements of the future village, and synthesis of the discussions.

Figure 5.9. Future Village Map.

VISUALISATION

BRIEF DESCRIPTION

This is a guided visualization exercise. Participants are arranged in a circle and asked to close their eyes and concentrate on breathing slowly to begin. Participants are then guided through a visualization of their village, their homestead, their home, and their daily calendar of activities in the future. Following the visualization, exercise participants tell the story of what they imagined for themselves successively around the circle, sharing desired futures. The group then collectively summarizes the visions and aspirations for development of the community. This exercise is able to capture non-tangible aspects of the future that are difficult to represent visually, such as gender relationships and other social conventions. The group prioritizes 3-4 aspects of the future vision for detailed planning on the following day of the workshop.

SPECIFIC OBJECTIVES

This exercise contributes to a 'rich picture' of the future in terms of local values and aspirations by capturing many aspects of daily life that cannot be represented graphically in a map or collage.

Figure 5.10. Participants Visualizing their Desired Future.

OUTPUT

The outputs of this activity are sets of narrative visions of a desirable future encompassing aspects of lifestyle, norms of representation and decision-making and values that are difficult to capture in physical representations of the future.

RESILIENCE PRIORITIZATION AND PLANNING

BRIEF DESCRIPTION

This activity is conducted with all workshop participants together. Participants discursively synthesize a 'rich picture' of their shared vision for a desirable future from the three distinct visioning activities and, from this, prioritize 3 to 4 key aspects of the desired future to be carried forward in backcasting by voting.

SPECIFIC OBJECTIVES

The primary purpose of this activity is for participants to select tangible outcomes that contribute to their desired futures, and which are practically oriented for backcasting.

OUTPUT

The output of this activity is a prioritized list of adaptation outcomes to be backcast on the following day.

5.7.3.2.2 Where we are now?: Asset-mapping

This phase maps, as completely as possible, all assets of individuals, local associations and institutions. It is essential that each person's gifts and assets be recognized, even the person who has been marginalized within the community. This releases the power of the individual and the community as a whole, and allows all of those affected to take ownership over the adaptation process. A similar process is followed with local associations both formal and informal. Formal associations, such as provincial administration, chief and village elders, religious groups or sporting clubs, can sometimes be easier to identify than informal associations, like youth groups, families or groups of friends. However, identifying informal associations is important to allow for the involvement of all stakeholders, to account for the multiple governance structures that exist in heterogeneous communities, and to promote the perception of legitimate processes.

RESOURCE MAPPING

BRIEF DESCRIPTION

This exercise is conducted in mixed or stratified groups (e.g., separate groups of men and women or separate groups of different age or income ranges) to collectively construct an overview or map of the biophysical resources available in the project location. The exercise is interactive and requires the participation of representative stakeholders that will draw the resources on a flip chart or use alternative materials to develop the map. Participants define the visualization of the biophysical resources. Facilitation requires explaining in very clear terms the steps and purpose of the mapping exercise. Once the maps are ready, facilitation is required to encourage discussion and analysis using the maps. This activity takes about one hour.

SPECIFIC OBJECTIVES

The exercise helps to identify the boundaries of the area to be assessed or project site, the different resources in the site and their spatial distribution. It can also be used to generate group discussions around issues like land tenure, resource allocation and management, use and benefits obtained from the resources and relationships between the different resources. This in turn helps to identify how sensitive people are to different climate hazards/stressors and what they have at their disposal for adapting to new conditions.

EXPECTED OUTCOMES

- Shared understanding among the participants about the resources in the site and their geographical location
- Clear spatial mapping of physical elements of the case study.
- Identification of key factors (i.e. institutional settings, customary rights and agreements, regulations, livelihoods, conflicts, etc.) that shape the relationships between the social actors and the biophysical resources in the site.

OUTPUT

The final products of this exercise are maps and tables drawn on flip charts, as well as a synthesis of the discussions.

Figure 5.11. Resource Mapping Output.

DAILY AND SEASONAL CALENDAR

BRIEF DESCRIPTION

Participants map out the seasons. For each season, participants map out their daily activities from waking to sleeping (maybe before sunrise and after sunset) for the three cases on the same diagram: of normal times, times of scarcity and times of abundance. The format facilitates comparison between activities during these times. Separate marks are drawn for the activities of men, women and children, also on the same diagram, and different colours can be used to facilitate the clarity of the diagram.

SPECIFIC OBJECTIVES

This activity aims to make clear daily labour and consumption patterns during times of scarcity, abundance and typical years, across the seasons.

OUTPUT

The exercise offers a very clear map of production and consumption patterns as well as adaptation mechanisms, by comparing the bands. Using the calendar, it is then possible to produce comprehensive lists of income generating activities used by participants; quantify crop yields and rates of crop failure; identify the sources and extent of livestock losses; determine the extent to which the participants have been reliant on emergency food aid and other services of government agencies and international organizations; develop a better sense of the division of labour; distinguish coping mechanisms that further degrade their environment and asset-base from those that are neutral or beneficial; and identify multiple stressors outside the biophysical drivers of food insecurity.

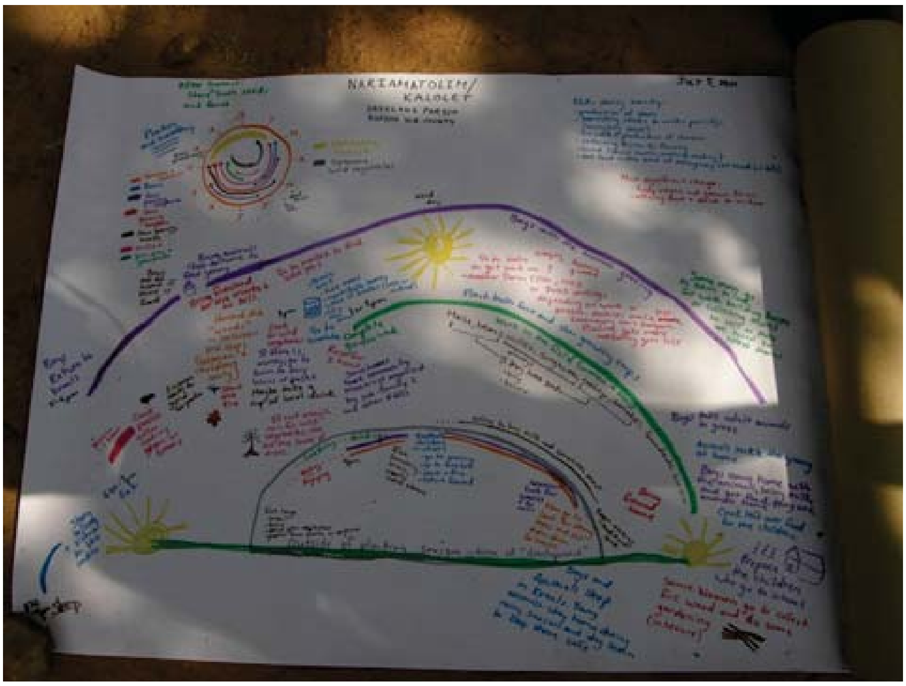


Figure 5.12. Seasonal and Daily Calendar.

FORMAL AND INFORMAL ORGANISATIONS AND INSTITUTIONS

BRIEF DESCRIPTION

Together the community lists all groups and organizations present and draws a diagram that represents the relationships between them. A Venn diagram is often appropriate, as shown in Figure 5.12. The activity includes local associations, both formal and informal, as well as related external agencies and individuals. Formal associations, such as provincial administration, chief and village elders, religious groups or sporting clubs, can sometimes be easier to identify than informal associations, like youth groups, families or groups of friends. However, identifying informal associations is important to allow for the involvement of all stakeholders, to account for multiple governance structures that exist in heterogeneous communities, and to promote the perception of legitimate processes.

SPECIFIC OBJECTIVES

The purpose of this exercise is to completely map out all of the formal and informal organisations and institutions that the community relates to and how these organisations relate to each other. This characterizes existing organisational and institutional capacity that the community has to build on, and which activities and resources can be coordinated through.

OUTPUT

The output of this activity is a visual map identifying all formal and informal organisations and institutions present and their relationships to each other and the community.

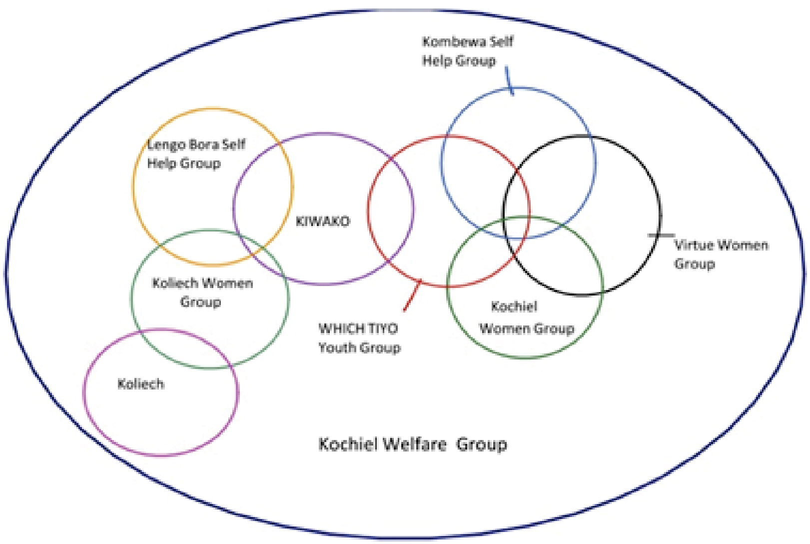


Figure 5.13. Formal and Informal Organizations Venn Diagram.

A sustainable livelihoods survey can also be conducted during lunch breaks to elicit information on the following:

Human Resources: This refers to skills and knowledge, and physical capacity. Examples include education, traditional knowledge, weaving skills, agricultural skills/training, skills in animal husbandry, cottage industry skills/training, health care skills/training, veterinary skills etc.

Natural Resources: This refers to the resources provided by the natural environment. Examples include trees (for building fuel, food and medicine), wild animals and fish, land etc.

Financial Resources: The stocks and flows of money that allow people to achieve their livelihood objectives. Examples include cash, savings, access to credit, access to markets, remittances, insurance, livestock etc.

Social Resources: Formal and informal organisations and institutions as well as netowkrs of social relationships social relationships that help individuals and the community to flourish. Examples are community groups, farmer groups, NGOs, religious organisations, government organisations etc.

Physical Resources: Human built infrastructure for energy, transport, communications, water, food etc. Examples include roads, water storage and distribution, machines such as tractors, cars, bicycles.

Box 2. Sustainable Livelihoods Framework

INDIVIDUAL STRENGTH MAPPING: COMMUNITY VALENTINES

BRIEF DESCRIPTION

Each participant writes an anonymous 'valentine' about one of the other participants. In the 'valentine' they detail all of the 'good things' about the other person. They can be skills such as carpentry, business skills, childcare or qualities such as honest, fair, kind or community perceptions of them, such as respected, important and so forth. Participants are instructed that nothing is too small and every quality is useful in the process of community development. The 'valentines' are returned by the facilitator to the person they were written about. Each person is asked to read their own 'valentine' to the group. This has a multitude of positive effects. Firstly, each participant leaves feeling happy and appreciated. The whole community becomes switched on to the skills and capabilities that exist within their community. The exercise builds trust, goodwill and relationships in the community. Ultimately a list is produced which allows the community to mobilise the resources they have for adaptation activities, based on these individual attributes.

SPECIFIC OBJECTIVES

This activity captures the skills, knowledge, expertise and assets of individuals. These aspects are crucial for backcasting building on existing strengths and assets and for assigning responsibility to particular individuals during backcasting. This is an amazing process; people are always smiling ear-to-ear while they read out their 'valentines'. Forums rarely exist for people to receive this kind of feedback and the outcomes are profound and multiple:

- Each participant goes home feeling happy and appreciated, which builds a general sense of well-being and goodwill.
- The exercise builds relationships between community members.
- The exercise identifies and mobilizes resources that are present within the community.

Figure 5.14. Numbers assigned during Individual Asset Mapping.

OUTPUT

This activity produces a mapping of individual skills, knowledge and assets within the community.

5.7.3.3. Day 3: Building a step-by-step plan

5.7.3.3.1 Backcasting with the support of relevant agencies

LINKING WITH SUPPORT ORGANISATIONS

BRIEF DESCRIPTION

Based on the activities thus far, including the goals and formal and informal institutional mapping, it is possible to identify sets of agencies that are potentially able to support the development and implementation of detailed community-driven plans. During the organisational and institutional mapping on day 2, contact details for each organization are collected. These points of contact can be called on the evening of day 2 to invite representatives to join on day 3 of the workshop. This is often possible since community identified representatives are often close by, and people that the community trusts. It is excellent if these representatives can participate in the initial backcasting, as a first stage in developing relationships, and also assist with planning at stages where the community needs assistance to identify options beyond their experience.

SPECIFIC OBJECTIVES

- To identify institutions with the capacity to support the community adaptation initiatives the community has identified.
- To invite representatives of these organisations to be present for the backcasting activity on day 3 of the Diagnostic, Prioritisation and Planning workshop so they can assist with details of the plans which relate to them and which require their input. They are not to dominate the process in any way; they are there to support.

OUTPUT

Relevant support agencies are present to assist with detailed planning process (backcasting).

BACKCASTING

BRIEF DESCRIPTION

Backcasting is a systematic process for working backwards from a desirable future to identify the steps required that connect the present to that future. We work backwards until we reach steps that are possible now. At each successive step backwards from the future, we ask the question, 'If we want to attain A, what would we need to do/have in place for that to be possible?' This question is over and over again asked until the answer is something that can be done in the present, so that, in reverse order, we have a step-by-step plan of how to achieve the desired future by building on present conditions. These steps can then be implemented successively, from where they are now, to achieve their desired future. People think like this all the time. For example, if I want to be at work by 9am, I will need to catch the bus at 8:30am, which means I will need to leave the house at 8am, which means I will need to finish breakfast and be packed by 8am, which means I need to be out of the shower by 7:30am and so forth. We are all familiar with the process of stepping backwards from a desired outcome to work out what would need to happen in a step-by-step fashion.

Backcasting is a method that focuses on the agency of people to overcome adversity and achieve their desired future, and the steps required to attain those conditions rather than taking steps that are merely a continuation of the current condition as in the case of forecasted planning. Working from the present, people are often blinded by their present difficulties and limitations. Working backwards from the future produces a huge spectrum of options people had not previously thought about.

Backcasting is usually implemented using a long sheet of paper and many post-it notes. The representations of the future created are placed at the right end of the sheet, and the representations of the current state placed on the left. Certain key features of the present and future are listed on post-it notes. We move successively from the right to the left continuously asking the question, 'What would we need/need to do to achieve this'?

SPECIFIC OBJECTIVES

This activity develops a step-by-step plan of how to reach desired future outcomes building on all that exists within a community, using all capacities they have to draw on.

Figure 5.15. Backcasting Activity.

Facilitation style for this process is very active and requires the facilitator to fully understand how backcasting works so they can actively help participants to think about options and steps. Supporting organisations are encouraged to assist the community to identify appropriate steps.

The facilitator is responsible for making sure the community does not get blocked on any item, such as not having enough money for something. In this case, the facilitator should encourage participants to think about all of the ways they could possibly obtain the required money, no matter how many steps it takes. There is always a way and, no matter where you are, it is always possible to take a step. This is the attitude that must be used when any obstacle is encountered – we simply think through all of the ways that obstacle could possibly be overcome and never let the group get stuck.

Box 3. Guidelines For Facilitating Backcasting

OUTCOME

This process produces a step-by-step community adaptation plan to achieve the community defined desirable vision of the future building on what exists and in the context of the challenges identified.

WORKSHOP EVALUATION QUESTIONNAIRE

- During the workshop:
    - What did you enjoy most?
    - Was there anything you did not like?
    - Was there anything that surprised you?
    - Was there anything you did not understand and needed further clarification?
- What could we do to improve the workshop?
- Do you have any reflections on the workshop you would like to share?

5.7.4. Post Workshop

FOLLOW UP INTERVIEWS

The results of the workshop should be cross-checked with individual follow-up interviews to ensure that specific perspectives have not been marginalized by the group process. Group processes are essential for community organizing and adaptation planning. However, it is unlikely that marginalized perspectives are adequately captured in a group process that is fundamentally good at capturing dominant shared perspectives. No method is a silver bullet and group versus individual techniques each have their own strengths and weaknesses; thus it is important to triangulate results.

In particular, 'hot topics' or issues where there is tension in the community need to be followed up individually, as these topics probably will not be freely discussed in a group setting. For example, access to specific resources can be a sensitive topic.

Some questions that can be used to guide follow-up are:

1. Did you feel your opinion was adequately captured during the workshop?
2. Were there any items you would like to comment on or add to?
3. Who has access to which areas?
4. Who does not benefit from customary rights to access resources in the area and why? (Indicate restrictions/barriers).
5. What property rights apply in the area?
6. What resources are managed under a legal contract? By whom?
7. What regulations apply on what areas?
8. What livelihoods depend on what resources?
9. What conflicts are there on natural resources?

Whom to follow up with:

1. People who didn't come – ask them why they didn't come, ask for their input on the topics covered in the workshop.
2. Marginalized groups who potentially could have found it difficult to express themselves in the workshop.
3. Where possible, a stratified sampling of all social groups to cross-check differences in frames, values, goals etc. is helpful but, as long as points 1 and 2 are covered, that should serve to capture the main issues.

5.7.5. Scenario Development

The challenges that characterize the context for many communities under pressure mean that the future is often impossible to predict. However, humans often base decisions and planning on the present or past or on largely unexamined assumptions of what the future will be like. The success of a plan depends on the context for which it has been developed; if that context changes, so does the usefulness of the plan. From a resilience perspective, the scenarios provide the 'to what' against which we test our plans in order to be resilient.

The development and use of scenarios allows individuals and communities to explore diverse, plausible (which means believable and consistent) futures and what challenges and opportunities they may pose for a community's plans. The result of a scenario development exercise is a set of diverse narratives (in words, numbers, images) about the future. Each scenario represents a future that is very different from the others in the set, to ensure that the scenario set offers distinct futures that test a community's plans against different eventualities. Seeing scenarios as a tool for testing plans is key – just like a car is not just tested on a smooth road but under extreme conditions, scenarios provide extreme futures to see whether a community's plans hold up under such conditions. Scenarios represent the 'adaptation to what?' question in the adaptation framework.

From an engagement perspective, scenario development is a highly engaging experience for communities because it takes on future uncertainties by letting participants create narratives that people can step into and imagine concretely – stimulating emotional engagement with the challenges and opportunities of the future. Scenarios also offer a tool for the integration of different types of information and have been reported to increase systems thinking in those who develop or use the scenarios. The entire scenario development process is a capacity development exercise. There are several different ways to develop scenarios, here are two options:

TWO-AXES APPROACH

BRIEF DESCRIPTION

The two-axes scenario development method structures scenarios by letting participants pick two uncertain factors of change (like environmental change, economic development, markets, political stability etc.) identified through a process of considering all of the factors of change relevant to their plans. They then determine two extreme states (stable or unstable markets, for instance) for each factor of change. The combination of these two factors yields four scenarios, as shown in Figure 5.15. This method can be used with any group because it is a wholly qualitative method based on intuitive analysis.

		Policy driver	
		Short-term priorities	Long-term priorities
Dominant Force	State Actors	Governments facilitate short-term gain: cash, carbon and calories	A slow and painful transition to sustainable states
	Non-state Actors	Ungoverned, quick and chaotic development; dealing with crises at the expense of investment	A struggle between civil society and the private sector that is ultimately productive

Figure 5.16. Four Scenarios for West Africa (CCAFS, 2011).

SPECIFIC OBJECTIVES

The goal of the two-axes scenario development method is to get to four distinct scenario narratives based on two change factors defined by two extreme states each. Together, the scenarios should represent diverse futures.

Figure 5.17. Participants clustering individual suggestions for factors of change, in a CCAFS scenarios workshop for South East Asia in Ha Long Bay, Vietnam, facilitated by the author.

OUTPUT

A stakeholder-driven analysis of key factors of change that affect their plans; a rating of the most relevant and uncertain factors of change; 4 (or less) scenario narratives (post-it timelines and narratives); possibly a specification of all factors of change within the set of 4 scenarios.

FIELD ANOMALY RELAXATION WITH SELECTION FOR DIVERSITY

BRIEF DESCRIPTION

This scenario development method follows many of the steps in the two-axes method but differs crucially in the use of factors of change to structure scenarios. The benefit of the approach is that it allows the use of more factors of change to structure scenarios, and more states for each factor of change – thereby opening up the scope of the scenario set. All factors of change are retained and participants define plausible states for each of these factors; there need not be a Euclidean distance metric between the states. Software called OLDFAR has been developed to choose the most diverse scenarios from the entire set of combinations of factors and states.

Factors	Markets	Enforcement capacity and regional collaboration	Agricultural investment	Land degradation through land use change
Land of the Golden Mekong	Common regulated market	Strong enforcement and strong regional collaboration	High public and private	Low
Buffalo, Buffalo	Unregulated	Weak enforcement and weak regional collaboration	Unbalanced: high private investment in business and research	High
The Doreki Dragon	Common regulated market	Strong enforcement and strong regional collaboration	Unbalanced: high private investment in business and research	High
Tigers on the Train	Protectionism and closed market	Strong enforcement and strong regional collaboration	Low public and private	Low

Figure 5.18. Four scenarios for South East Asia (CCAFS, 2011)

Version 1 of OLDFAR and the associated scenario methodology was developed by the author of this thesis for the CCAFS scenario activities in South Asia and was further developed into its current form available online by Dr. Steven Lord. For the OLDFAR program and additional information on this variation of scenario development please see CCAFS Regional Scenarios website (CCAFS, 2011).

SPECIFIC OBJECTIVES

To outline factors of change for a given group's decision context and develop scenarios based on this scope.

OUTPUT

A stakeholder-driven analysis of factors of change; an analysis of the possibility of state combinations; 3 to 6 scenario timelines and narratives; an analysis of the direction of change for all factors of change identified by participants across the different scenarios.

5.7.6. Robust Planning Through Scenario Testing

REVISED BACKCASTING IN THE CONTEXT OF EACH SCENARIO

BRIEF DESCRIPTION

Scenarios developed through the method described above, or adapted from an existing set of scenarios, can be used to test and revise/improve plans developed through backward planning or backcasting. Scenarios can be used to test whether a given plan is robust or flexible enough to be feasible under different extreme scenarios, and also to determine whether the plan is concrete, detailed and complete enough.

It is important that those who plan to use scenarios to test and improve their plans are familiar with the scenarios. If the users of the scenarios are also the people who created them, that is great. In cases where the group uses an unfamiliar set of scenarios, spend some time (an hour at the very least) reviewing and adapting the scenarios, using the following questions:

- Are the scenarios relevant for decision-making in our group? How can they be made more relevant?
- Are the scenarios plausible (believable and internally consistent)? How can they be made more plausible?

Assuming that the group knows the scenarios they will be using, they examine the results of their backcasting exercise in the context of a scenario. This can be done by putting the backcast plan up on a table or the wall, and picking a colour of post-its for each scenario. Then, examining the objective/vision at the end of the backcast plan, and each step toward that end point, participants ask 'at this time in the scenario, what would be the challenges we would be facing when trying to execute this plan, and what opportunities may be available?' The group writes these down on the coloured post-its and adds the post-its to the backcast timeline.

Then, the group discusses how the planning could be changed to overcome these challenges and opportunities that are offered by the scenario and adds them to the timeline. For this exercise, the larger group can either be split up into breakout groups, each using a copy of the backcast planning timeline and testing it against one scenario; or alternatively the group can test the planning against multiple scenarios in a row together. In both cases, what emerges is a collection of ways in which the planning can be improved to be more robust, flexible, concrete and complete in the face of different scenarios.

Together, the group analyses which elements of the basic plan and its improvements are 'no regrets' options that work under all scenarios, and which elements of the plan and its suggested improvements only work under certain scenarios. Based on this analysis, the group revises their basic planning and adds a portfolio of options for specific eventualities (scenarios) to the plan.

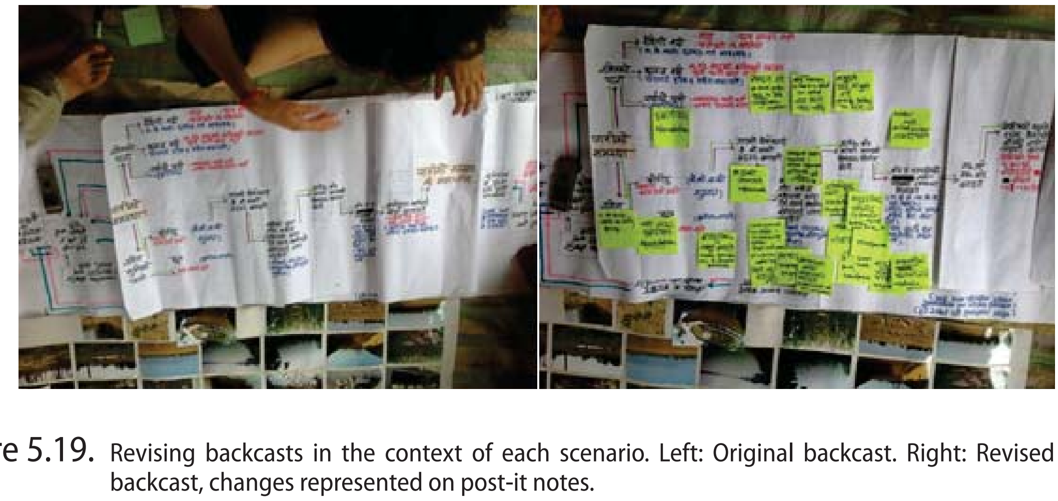


Figure 5.19. Revising backcasts in the context of each scenario. Left: Original backcast. Right: Revised backcast, changes represented on post-it notes.

SPECIFIC OBJECTIVES

- To test and improve community plans by challenging them with multiple scenarios.
- To build community capacity for decision-making and planning under uncertainty and change (that is, adaptive capacity development).

OUTPUT

An analysis of the strengths and weaknesses of a backcast planning timeline under different scenarios; a revised/improved backcast planning timeline, including basic improvements that work across all scenarios and a portfolio of options that are specific to certain eventualities.

Many of the more general tips for facilitation also apply to facilitating the development of scenarios and their use in backcasting processes.

However, there are some specific things to consider when facilitating scenario processes:

- People are often only used to thinking about the questions 'what future do I want to happen', considering a desirable future vision, or 'what future is most likely to happen' – attempts to predict the future. Because scenarios, as used in this manual, are neither visions nor predictions, it is important to explain this clearly to participants. Emphasizing that scenarios are meant to be diverse and extreme so they can be used to test plans helps with this. It explains why we are not talking about what is most likely to happen. It also explains why we are not including a 'would like to see' vision of the future, since the feasibility of that vision and the steps toward it should be tested using the scenarios, and this is not possible if the vision is already happening in one of the scenarios. Pay attention to people's tendencies to discuss the most likely futures or desirable future visions throughout the process.
- Once the analysis of key factors of change and states is over and scenarios have been selected, scenario development is really an experiential group storytelling process. Stimulate participants to really imagine what the futures they are exploring would be like to help give them inspiration to make the scenarios vivid and salient. Asking participants to think of the scenario narrative as a movie or history of the future can help.
- Be aware that scenarios are a tool for stretching participants' biases about the future and this is not an easy process. Prompting questions to help participants consider a broad spectrum of future changes is useful.

Box 4. Guidelines For Facilitating Scenario Activities

5.7.7. Facilitator Guidelines

The following list of qualities of the facilitator is ultimately more important than any specific method or tool. There is a role for expertise in facilitation, as lack of facilitation skills can alienate a community and have seriously negative impacts on adaptation collaborations.

1. **Relax, be flexible, and avoid being dogmatic.** Practitioners of participatory techniques must learn rapidly and progressively, with conscious exploration, flexible use of methods, improvisation, iteration and cross-checking, not following a blue-print program but adapting in a learning process. It is important to stay relaxed as participants absorb any tension in the facilitator and this has a very negative impact on their ability to share, think, learn, buy-in to the process and the research and practice outcomes.

2. **Be sensitive to context.** Adjust your approach to take account of every new context. Do not be tempted to assume that what has been appropriate in previous experience is applicable without first considering the differences in time, location, culture, size, historical juncture, perceptions and expectations of the target community. Continuously monitor and evaluate your approach and adjust it accordingly.

3. **Approach each situation with humility and respect.** Adaptation is a highly complex and multi-dimensional issue, beyond the full comprehension of single individuals or experts. Appropriate adaptation strategies require engagement of as many diverse stakeholders as possible in order to minimise unexpected deleterious consequences of intervention. This process begins with awareness and respect that each person brings unique skills and knowledge, and that the experience and formal education researchers and experts bring to a process are valuable but limited. People who have lived their whole lives in communities and who have a direct stake in the outcome of an intervention have vital knowledge to contribute.

4. **Shared and reversed learning.** It follows from the principle of respect above that practitioners should be prepared to learn from others in ways they had not planned. This involves changing behaviour and attitudes, from dominating to facilitating, gaining rapport, asking people to teach us, respecting them, having confidence that they can do it.

5. **Acknowledge different ways of knowing and understand the potential of local knowledge.** Be prepared to accept and value expression of knowledge in ways that differ from traditional, scientific, European-based logic and knowledge systems. There exists a tremendous diversity of knowledge systems in different communities, including local experiential knowledge, intuitive knowledge, and traditional knowledge.

6. **The variety of stakeholders, and the relations between them, matter.** Consider the power dynamics, inequalities and norms of expression and decision-making that exist before attempting to engage people as a group. Be sensitive to techniques that engage marginalised groups (e.g. separate engagement with female members, or engagement with groups along hierarchical lines). Also, be aware of the potential personal consequences for information providers, if those in power are challenged. Techniques need to be employed which take into account existing norms and social structures in an appropriate way.

7. **Respect the will not to participate.** Part of demonstrating respect and building trust in any community is accepting the right of any member to choose not to participate.

You may seek to discover why someone chooses not to participate in order to identify potential problems like participation fatigue, power differences and inequality within the community.

8. **Be self-aware, practice active listening and continually reflect.** Practitioners must have critical self-awareness and take responsibility for their actions and judgements. This includes reflection on the possible impacts of preconceived notions and participation in the research or action process. Facilitators should continuously examine their behaviour, and try to improve.

9. **Embrace uncertainty.** This may be necessary throughout the engagement process where participation, input and outcomes may differ from what you planned. It is important to understand that concrete answers do not always exist. The introduction of information with high degrees of uncertainty may be a cue for the research to investigate in a different direction.

5.8. Conclusion

In order to meaningfully operationalize the concept of resilience in practice, whether we are seeking to understand it, manage it, or measure it, resilience 'of what, to what, from whose perspective and over what time frame' must be specified. The answers to these key questions recursively depend on each other and do not have simple answers, since the boundaries of systems are not given objectively and unproblematically by the structure of reality; all involved experts or stakeholders will have slightly different opinions and justifications for how they would like to see these key questions answered. Accordingly, exploring the answers to these questions involves iterative participatory processes that are, themselves, capacity development interventions.

This chapter has provided an operational framework for meaningfully characterising, measuring and even building resilience in practice. The framework involves the following principles:

- Strength-based participatory multi-stakeholder processes to explore the framing of resilience.
- Interdisciplinary teams of resilience researchers working together which each other and affected stakeholders to undertake boundary critique.
- Theoretical and methodological pluralism.
- Pluralism in facilitation, in the modes of representation used, the tools applied, and the understanding of the client.
- Humility.

In keeping with these principles, the operational framework presented here does not specify which particular methods must always be used to answer the key questions which frame resilience. Practitioners are encouraged to work in interdisciplinary/inter-sectoral groups, together with stakeholders, to co-design appropriate methodologies for joint inquiry, analysis, intervention and monitoring and evaluation.

Any specific methods and tools can be applied to explore the framing and characterization of resilience in practice. This thesis gives examples of some specific instantiations of the operational framework presented here in practice. It is highlighted that the framework is transferable and any sets of appropriate methods can be used to identify resilience 'of what, to what, from whose perspective, over what time frame' including what constitutes desirable change to whom and all of the relevant questions that go into understanding and modeling resilience. Practitioners should work with stakeholders to design appropriate methods to address the key issues in framing and planning for resilience. An example of one particular instantiation of the operational framework has been provided in the form of a field methodology: the 3-day diagnostic, prioritization and planning workshop and its follow- up scenario development and testing process (which can be done in 2 days). The manual for this entire process has been published as CCAFS Working Paper 76 (Helfgott et al., 2014). The manual also provides a suite of additional activities that can be substituted for these illustrative examples as well as guidelines for dealing with conflicts and monitoring and evaluation.

Chapter 6 gives a case study of the operational framework including the 3-day workshop and scenario process, in Nepal. Chapter 7 illustrates the operational framework and applies the mathematical framework for measuring resilience. Chapter 8 applies the operational framework to resilience research program design.

6.

Understanding and Managing Resilience

6. Understanding and Managing Resilience

6.1. Introduction

This chapter describes a case study of applying the operational framework presented in Chapter 5 to understanding and managing the resilience of agricultural communities to climate change on the Terai plains of Nepal. Many agricultural communities have long standing traditions of resilience and adaptation. However, the current speed and magnitude of environmental change threatens to overwhelm traditional mechanisms (Adger et al., 2003, Parry, 2009). The program described in this Chapter was designed and implemented to address these issues.

The author drew together an interdisciplinary team of researchers composed of an anthropologist, economist, political scientist, ecologist/biologist and the author herself in an integrative role as a systems thinker and project leader. This team conducted action research into resilience to climate change together with local communities, government and non-government agencies in Nepal in 2012. The diagnostic and planning workshop described in Chapter 5 was implemented in order to frame resilience in local terms, including what constitutes desirable change or improvement. A novel experiential scenario exercise was conducted and used to break down assumptions about the future that hinder resilience and adaptive capacity, test the plans against a diverse range of 'to what' scenarios, generate an enhanced portfolio of options for the community to draw upon and increase strategic capacity for decision-making under uncertainty and change.

The scenario activity was based on using farmer exchanges to diverse plausible future climate analogues. The CGIAR research program on Climate Change, Agriculture and Food Security (CCAFS) in collaboration with the University of Leeds and the Walker Institute developed CCAFS Climate Analogue Tool (CAT). The CAT uses General Circulation Model(GCM) ensembles and current climate data sets in unison to connect sites with statistically similar climates, across space and/or time and uses Geographic Information Systems (GIS) software to visually map analogues (Ramírez-Villegas et al., 2011)[1] . The team was tasked by CCAFS[2] with using the CAT to inform a series of farmer exchanges to develop resilience and adaptive capacity of farmers to climate change, the author had the freedom to design the methodology for its use and its incorporation in the program. This program

[1] Note that a variety of planning tools have surfaced as a product of the urgency of climate adaptation issues DESSAI, S., LU, X. & RISBEY, J. S. 2005. On the role of climate scenarios for adaptation planning. Global Environmental Change, 15, 87-97, WILBY, R. L., TRONI, J., BIOT, Y., TEDD, L., HEWITSON, B. C., SMITH, D. M. & SUTTON, R. T. 2009. A review of climate risk information for adaptation and development planning. International Journal of Climatology, 29, 1193-1215, SCHIPPER, L., LIU, W., KRAWANCHID, D. & CHANTHY, S. 2010. Review of climate change adaptation methods and tools. . MRC Technical Paper. Vientiane: Mekong River Commission.. In the majority of cases, climate information is provided by Global Climate Models (GCMs), downscaled to geographical resolutions feasible for adaptation planning. Climate analogues represent an emerging variety of downscaled GCM-based adaptation planning tools RAMÍREZ-VILLEGAS, J., LAU, C., KÖHLER, A.-K., SIGNER, J., JARVIS, A., ARNELL, N., OSBORNE, T. & HOOKER, J. 2011. Climate analogues: finding tomorrow's agriculture today. Cali, Colombia: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), HALLEGATTE, S., HOURCADE, J.-C. & AMBROSI, P. 2007. Using climate analogues for assessing climate change economic impacts in urban areas. Climatic Change, 82, 47-60, KOPF, S., HA-DUONG, M. & HALLEGATE, S. 2008. Using maps of city analogues to display and interpret climate change scenarios and their uncertainty. Nat. Hazards Earth Syst. Sci., 8.

[2] CCAFS funded this research

is hereafter referred to as Farms of the Future (FOTF). The CAT and its development are described in other publications (Ramírez-Villegas et al., 2011).

Often approaches based around the use of climate models to provide improved estimates of future climates fall into the category of expert and data driven, vulnerability-based adaptation plans aimed at reducing uncertainty and sector-based risks, such as the IPCC scenarios (Van Notten, Rotmans et al. 2001, IPCC 2007, Wilkinson and Eidinow 2008). Six decades of agricultural development indicate that purely expert driven, top down, problem-based approaches are likely to have adverse effects on agricultural communities in developing countries (Kretzmann and McKnight 1993, Copperrider and Whitney 1999, Mikkelsen 2005, Helfgott 2008). The FOTF methodology presented here is unique in that it marries technical-analytical approaches with sociological-hermeneutic and critical systems thinking approaches within a reflexive post-normal framework. The methodology presented here is a participatory, multi-stakeholder, resilience/strength-based, integrated, critically reflexive, approach that embraces the uncertainty as more than a lack of knowledge or data.

Farmer exchanges based on the CAT are a seductively marketable concept, particularly if framed as "showing farmers their future", as has been the case in a number of popular media articles. In our experience, this is a highly problematic framing. In this Chapter, we argue that, based on the characteristics of the tool itself and general insights about the limitations of prediction in the context of adaptation of small-holder farmers to global change, the CAT should be used to generate multiple "plausible" futures (Moss, Edmonds et al. 2010) within a program designed to build strategic capacity and to break down assumptions about the future which hinder adaptive capacity; rather than to "allow farmers to 'see' into the future" (Bafana 2011) by showing them "what their probably future climate will be like" (Thiong'o, Ouna et al. 2012). This Chapter describes the program that was designed and implemented to capitalize on the opportunities provided by the CAT, at CCAFS request, recognize and work with its limitations, and build adaptive capacity to climate change and related uncertainties with the stakeholders involved.

FOTF was designed to provide the participant community with access to an increased set of adaptation options, promote knowledge sharing between farming communities and build adaptive capacity to climate change and related uncertainties. The approach taken was participatory, multi-stakeholder, strength-based, integrated and critically reflexive. This paper presents the theoretical framework, operational methodology, results and discussion. The discussion includes guidelines for responsible use of the CAT, for farmer exchanges in general, and for development of resilience and adaptive capacity at community level. The 2012 FOTF pilot was carried out as part of a broader research Program known as Systemic Integrated Resilience and Adaptation (SIRA) research program. The SIRA program as a whole is described in detail in Chapter 8, aspects of it are summarized briefly as required.

6.2. Theoretical Framework

The theoretical framework for the entire program is provided in Chapters 4 and 5. This section deals specifically with the theoretical framework for the farmer exchanges to climate analogue locations as exploratory scenario exercises. The term exploratory is used to refer to scenarios that explore 'what could plausibly happen', rather than describe 'what will probably happen' or 'what is desirable to happen'(Börjeson et al., 2006). Three exchange locations, each as different as different from each other in as many relevant dimensions as possible while still being feasible and socially appropriate, form the basis of three exploratory scenarios. As such, the exchanges and associated scenarios are used to break down expectations and assumptions about the way the future is going to be and open up possibilities (Wilkinson and Eidinow, 2008, Ramírez and Ravetz, 2011).

The community's shared normative goals are back-cast in the context of each scenario, generating different sets of actions, as each scenario contains different challenges and opportunities as illustrated in Figure 6.1. The combination of normative back-casting and exploratory scenarios tests the robustness of an increased set of adaptation actions in a diverse range of contexts, and builds capacity for planning and decision-making under uncertainty and change (Kok et al., 2011, Robinson et al., 2011, Chaudhury et al., 2012).

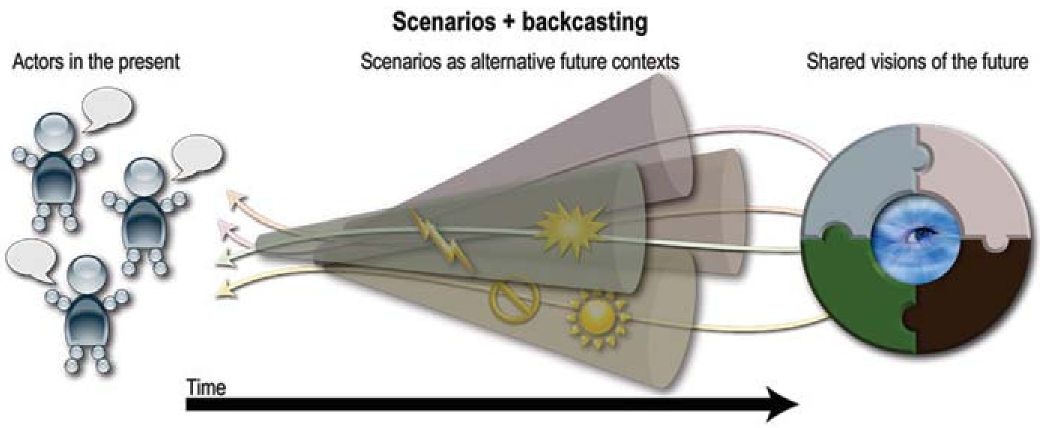


Figure 6.1. Exchange scenarios provide alternative contexts for back-casting.

In the process shown above, participants aspire to steward the system towards desirable outcomes and away from undesirable ones, across a broad range of diverse plausible future scenarios. This matches the understanding of resilience as the capacity of a system to maintain or create desirable states and avoid undesirable states, which has been discussed throughout this thesis(Walker et al., 2006, Folke, 2006). Thus, the process represents a resilience-planning approach, based on the acknowledgement that it is impossible to predict, still less control, all of the sources of change that affect the linked social, economic, political and environmental systems in which smallholder farmers are embedded.

Strength-based approaches that build on existing knowledge, skills and resources extant within the community, rather than leveraging external knowledge and resources, are more likely to empower the community and generate resilience and adaptive capacity from within (Helfgott, 2008).Thus, the framework of Appreciative Inquiry was used to structure community planning activities in combination with the scenario planning approaches.

Effecting a transition towards sustainability involves challenging unsustainable practices (Mermet, 2011). The future is a safer space to challenge the status quo than the present because there is less buy-in to a very specific vision of the future (Wilkinson and Eidinow, 2008). The exchange/scenario process is used to challenge assumptions about the future and the status quo and to provide a safe space for marginalised voices to express their needs and aspirations in the future space. Community collaboration and harmony are built through planning and normative visioning activities. Balance is achieved by alternating within the process between shared planning and critical reflexive activities, repeatedly, across three exchange scenario exercises.

6.3. Methodology

The methodology for the FOTF follows the stages described in Figure 6.2 below. Each of these stages will be described briefly.

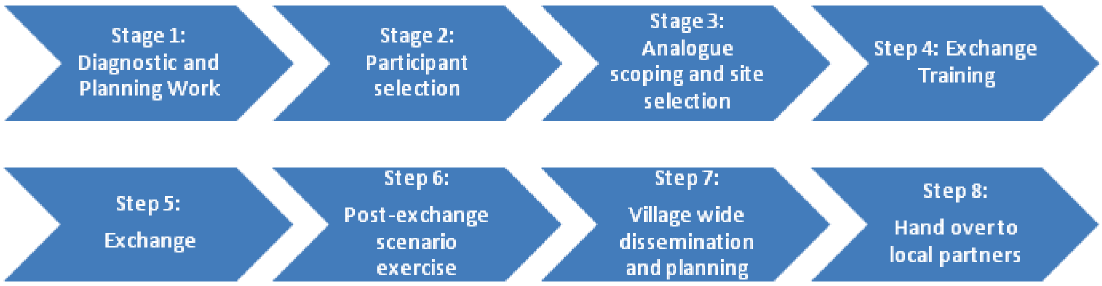


Figure 6.2. Methodology for analogue exchanges as exploratory scenarios

6.3.1. Diagnostic Work

6.3.1.1. Preliminary Ethnographic Work

Team members lived in the reference village, conducting preliminary ethnographic work for a period of one month prior to commencement of formal activities. Extant forms of social differentiation in the village were established as well as social norms of representation, decision-making and activity as they relate to various social groups. This information was used to design participant composition and choice of activities as part of the FOTF program.

6.3.1.2. Village-wide Diagnostic and Planning Workshop

The 3-day, village wide diagnostic and planning workshop described in Chapter 5, attended by around 100 people representing all social groups within the village, was used to conduct a joint systemic analysis of:

- Scope of the system under consideration (resilience of what): Card-clustering exercise on 'What's Important' to the community as a whole established a broad conceptualization of the system of interest. Clustering exercises around adaptation challenges and responses serve to further refine the system of interest with respect to resilience and adaptation.

- Key challenges facing the community and their interrelationships (resilience to what): Challenges Clustering Exercise established key sets of adaptation challenges. A causal mapping exercise elucidated the relationships between these challenges and factors that underpin adaptive capacity. Challenges were ranked to aid prioritization of learning and development activities.

- Local values, visions and aspirations for the future, what is desirable and undesirable to whom (resilience from whose perspective): The 'What's Important' clustering exercise and its associated discussions gave an indication of local values. Visioning exercises, including collages, map of future village and narrative visions, elucidate aspirations and desirable futures.

- Existing coping strategies and tools, strengths and assets in the community (appropriate actions build on present strengths and existing capacities): Appreciative Inquiry and Asset-Based Community Development were used to identify current knowledge, skills and resources from individual through households, groups, to community level and surrounding environment. Sustainable Livelihoods Assessment, Current Village map, Organizational and Institutional Mapping (formal and informal) and Community Valentines were conducted.

Based on this, a strategic plan that builds on locally available strengths and resources to reach community-identified goals and visions is developed through back-casting. Participants prioritized aspects of their desirable future to back-cast. These aspects were kept abstract (e.g. adequate water for irrigation) to avoid lock-into particular solutions. Subject matter experts and representatives of organizations with potential to support the implementation of back-casted plans were present to assist.

The most important function of this initial back-casting exercise for FOTF is to capture the common implicit future scenario by surfacing assumptions about what is feasible or not and why. It serves as a baseline that allows the analyst to observe changes in thinking that occur as a result of the subsequent farmer exchanges. These changes are elucidated through comparison of the initial back-casts with those after the exploratory scenario exercises. The initial back-casting also gives participants an opportunity to express their own 'pet peeves' and 'pet actions', allowing them to get these on the table so they are freed up in preparation for subsequent exploratory exercises.

The community-priorities-shaped exchange site selection is to ensure exchange program alignment with local values and aspirations for learning and development, rather than imposition of the external values of the team. The workshop closed with notification and motivation of the exchange program and of the participant selection procedure. The workshop was followed up with one-on-one interviews to cross- check results.

6.3.2. Participant Selection

All community members nominated exchange participants considered the best for knowledge exchange with the entire village. Consideration was given to the representation of sub groups within the community. Each exchange had different participants, maximizing the number of people who have a direct learning experience and can transfer knowledge to the broader community, plus with one common participant for comparative purposes.

6.3.3. Analogue Scoping Trip and Exchange Site Selection

CCAFS provided climate analogue maps for the reference village to the year 2030. Program participants considered this the longest possible planning horizon. A total of 12 analogue runs were provided to the research team. Each run consisted of different combinations of the following:

- Climatic variables (e.g. rainfall, temperature, or both)
- Seasonal periods (e.g. matching variables for only the growing season or the whole year)
- Relative thresholds (e.g. the level of statistical dissimilarity from the reference site within the probability distribution that qualifies a site as analogous)
- Uncertainty measures (e.g. limiting the number of analogous sites by eliminating those locations with an uncertainty measure greater than that specified by the user)

Google Earth layers containing the analogue maps were overlaid on road network and topographic maps. Five zones located within a 200km radius of the reference community representing the entire range of analogue output results were selected for scoping. 200km represents a full-day bus ride in this terrain and travelling further was not feasible.

Two weeks were dedicated to driving throughout the mapped analogue regions, visiting every possible village within that scope. A rapid appraisal was conducted using a mixture of transect walks, semi-structured interviews and Rapid Rural Appraisal focus groups to establish:

- Willingness and capacity to host an exchange.
- Social, cultural, political, economic and environmental appropriateness as an exchange site with the reference village. This includes, among many other issues, tensions between caste and ethnicity and language.
- Potential for learning and exchange, including degree of exposure to different adaptation options and presence of features identified as learning priorities by the reference village.
- Largest possible diversity of plausible futures represented across possible exchange sites. This diversity was somewhat limited by the diversity available within the analogue maps and disconnects between those maps and intuitive analogues. Diversity was sought in as many social, political, technological, environmental and economic dimensions as possible while maintaining the social and cultural appropriateness of the exchange for the participants and the possibility that they could extract a plausible future for themselves from this experience.

6.3.4. Exchange Training

Training of the exchange participants took place over four days, for two hours in each morning, and was designed to achieve the following objectives:

- Describe the exchange procedure, roles and responsibilities.
- Participants were given flip cameras, trained how to use them and instructed to take footage of those aspects of their lives they would like to share with the exchange village. They were also instructed to film their experience of the exchange to facilitate dissemination on return from the exchange.
- Teach participants about climate change and the meaning of the exchange, ensuring participants understood that exchange locations represented plausible futures rather than predictions or prophecies: Most Significant Change technique was used to contextualise climate within multiple forms of change and uncertainty already facing the community(Willetts and Crawford, 2007). Brainstorming and clustering exercises around two themes, 'Climate change, what we know' and 'Climate change, our questions', allowed the team to facilitate a discussion of the science of climate change at the appropriate level for participants, plugging any gaps in understanding accordingly. Past and present seasonal maps were constructed to examine perceptions of climate changes and impacts thereof.
- Training on decision-making under uncertainty: brainstormed and ranked climate-related decisions, conducted decision-tree analysis of top-ranked climate related process. Identified available sources of information, where more information was required, discussed sources of uncertainty and methods of coping.
- Develop participants' critical thinking skills to manage risks of adopting unsustainable or undesirable features of the exchange location: Four stage critical thinking training process: 1) Believing game, 2) Doubting game, 3) Defining, 4) Reports and Judgements based on the work of Peter Elbow and Alan Shapiro (Elbow and Shapiro, 2011). The aim of this four-stage process was to produce a recognition of complexity, a sense of the strength and worth of a position not one's own; an ability to cope with diversity and uncertainty, a desire to go on thinking.
- Develop participants' ability to question assumptions: Discussion facilitated around expectations and assumptions to assist with critical thought and learning on the exchange and openness to exploration of future plausibilities.

6.3.5. Exchange

During the exchange, host farmers demonstrated land and water management practices as well as broader lifestyle features; exchange farmers shared films, stories and practical knowledge. The facilitated activities included:

- Walking tours demonstrating local practices.
- Past and present seasonal calendar and discussion around changing climates in both villages, shown in Figure 6.3.

- Resilience challenges and responses exercises, examining what has worked and what hasn't and why.

- Films made by exchange participants with facilitated discussion.
  Surveys and interviews were conducted on the bus to and from the exchange and, at the close of each day to evaluate impact. This process was repeated three times in three diverse analogue sites.

Figure 6.3. Exploring perceptions of climate change: comparing past and present seasonal maps of the reference and exchange communities.

6.3.6. Post-exchange Scenario Exercise

Similarities and differences exercise: Following each exchange, a plausible future scenario for Beora was extracted from the exchange experience. Participants reflected on aspects of the exchange location that were similar or different. The items that were different were divided into two further categories: aspects that are incommensurable and aspects that are different now, but could plausibly happen in the future. The aspects that were considered incommensurable were removed from the future scenario.

Scenario creation: From the list of similarities and plausible differences, a description of a plausible future for the initial village was created from each exchange. Those aspects which were different yet plausible were retained, and participants were asked to imagine and discuss what Beora would look like if those aspects came to pass. Photos the participants had taken on the exchange, representing plausible aspects of the future, were used to make a collage and build a picture representing the future scenario. There were three scenarios in total, corresponding to each of three exchanges.

Revised backcasting: The initial backcasting was revised in the context of each exchange scenario. Activities that were no longer feasible or became redundant were removed, new options learned during the exchange were included and new opportunities capitalized on. This process was repeated after each exchange.

6.3.7. Village-wide Dissemination and Planning

A workshop was conducted for village wide dissemination and planning. Each exchange group reported on their exchange scenario process: sharing key lessons learned, showing films made from exchange footage and presenting their revised backcasts. Each backcast was revised and agreement on final plans negotiated. A plan to continue revisiting and revising was also laid out. External agencies and NGOs with the potential to support the plans were present for the entire workshop. Responsibility was assigned to appropriate individuals/groups for ensuring the continuation of the planning and implementation process.

6.3.8. Handover to Local Partners

A key dimension of the methodology is succession planning and linking with institutions capable of supporting the plans and actions of the community. It was important to link the activities of the FOTF program with ongoing action to avoid disillusionment and disempowerment in the community. The allocation of seed funding was included in the program to ensure this by facilitating immediate actions identified in the strategic plan to continue project momentum. The village was given 1000 USD as 'seed money' after the planning and prioritization process was completed. They did not know about this money until that time. Appropriate agencies were identified through which to channel the seed funds.

The team returned in one year and two years to assess progress with the support of local partners. The success of this program handover was assessed after one year using Most Significant Change focus groups with villagers and members of partner organizations, semi-structured interviews and transect walks in Beora.

6.4. Results

A detailed report of all results of the program, including detailed ethnographic data, is provided in the CCAFS report on the Nepal Pilot Program (Bailey et al., 2012).

The Rupandehi district of Nepal was chosen as a focal area, due to its agricultural significance for Nepal combined with its vulnerability to climate change. The primary crop of rice is already very close to its upper temperature threshold and temperatures in the area are predicted to rise further. The village of Beora was chosen within Rupandehi, based on enthusiasm to take part in the program and the presence of local partners in an ongoing relationship with the community to ensure the research was not extractive.

Figure 6.4. Map showing Beora, Rupandehi, Nepal: the reference site for the FOTF.

6.4.1. Diagnostic Work

6.4.1.1. Preliminary Ethnographic Work

Preliminary ethnographic work revealed that Beora is composed of 118 households: 10 of the minority Yadav caste, 8 of Dalit (untouchables), 4 of upper castes (either Chetri or Brahman), 96 are of the Tharu indigenous ethnic group. Beora is a community of smallholder farmers, whose major crop is rice. Some livelihood diversification exists, such as factory work, construction, fishing and teaching. Many male heads of households travel overseas to earn money and send home remittances. Many rarely return home, over decades, leaving many female heads of farms.

6.4.1.2. Village-wide Diagnostic and Planning Workshop

Resilience and Adaptation Challenges

Beora's shared perception of the top 10 ranked resilience and adaptation challenges facing the village are:

1. Lack of education: makes it difficult to improve and adapt farming, add value to products or diversify livelihoods for resilience.
2. Inadequate water for irrigation: leads to crop failure.
3. Poor fertilizer availability: relates to poor crop yield compounded by declining soil quality.
4. Low market prices: cannot break out of poverty trap with current farm-based livelihoods.
5. Rising Temperatures: threatens crop yield, leads to fatigue and illness.

6. High input prices: relates to both poor crop yield and to poverty.
7. Deforestation and lack of trees: affects water and temperature regulation and also sources of building materials and fuel. These relate to crop yield, health and poverty.
8. Poor health: makes it difficult to work and to carry out desired adaptation actions.
9. Poor seed availability plus loss of indigenous seeds: limits sustainable farming techniques, creates dependence on limited seed supplied, affects crop yield.
10. Pests and diseases: reported to be increasing with temperature, affects crop yield, food security and livelihoods.

Response Strategies and Tools

The community revealed a large number of existing responses to these challenges, as well as many they are open to but have not yet tried to implement. Many responses were deemed within reach with some community planning and action. These responses included adult knowledge sharing schemes, programs to better clean and maintain channels which divert water from the river; boreholes, pumps and irrigation channels, planting trees, producing home-made fertilizers, crop diversification, income diversification and saving schemes, seed banks for traditional and new seed varieties.

Future Visions

The community articulated visions for the future of Beora in the form of a detailed map of the future village, a collage showing features of their desired future and a set of narrative visions Figure 6.5. Based on common aspects of the visioning and a voting exercise three distinct aspects of the future were prioritised for backcasting:

1. Improved soil quality and pest management
2. Increased agricultural production
3. Adequate water for irrigation

Figure 6.5. Detailed map and collage of community vision of the future of Beora.

Current Asset-mapping

The full current asset-mapping can be found in the CCAFS Nepal Farms of the Future Pilot Report (Bailey et al., 2012), only a few illustrative points will be mentioned here:

- Beora relies predominantly on rain for irrigation. They have a canal from the nearby Tinau River. As the village joined the water-sharing group late and are downstream of many villages they receive very minimal water. The village is in the proximity of the Rohini River; however, it is too far to draw water from without major infrastructure.
- Since the Maoist revolution, there have not been elections for village leadership. The village desires greater coordination, and villagers are keen to begin community-organizing initiatives around goals and visions;thus there is a great deal of goodwill. Various community groups exist and there are a number of ongoing relationships with NGOs and government agencies.
- The village relies on government supplied chemical fertilizer, which can be unreliable, and this year failed entirely. Soil quality has been declining, which is attributed to the use of chemical fertilizers and a decline in the number of livestock.

Backcasts

To facilitate description, the plan developed through each backcasting exercise is described in chronological sequence of actions, though the process of developing the plan occurred in the reverse order.

Backcast 1: Improved soil quality and pest management

To achieve improved soil quality and pest management, the community draws on three currently available resources, land', 'farming knowledge' and 'hard-working people'. The intervention begins with the development of a forum for knowledge sharing and pooling of resources. This forum is designed to centralize technical knowledge available within the community on how to measure soil quality and to share pest management strategies. The community envisioned improving coordination to solicit external support and expertise. In particular, they identified the need for soil quality measurement and support in Integrated Pest Management.

Backcast 2: Increased agricultural productivity

Three management practices were envisioned by the community to increase both the quality and the quantity (75% anticipated yield increase) of rice production within Beora, allowing the community to compete with Indian subsidy pricing, and react to rainfall variability, among other benefits. These are: seed varietal selection, water use, and fertilizer application. To plan for this broad list of interventions, the group shortlisted rice as the target crop, as it represents the primary contributor to Beora's economic livelihood. To better understand their varietal options, they planned to approach market staff, informed neighbours, government actors, Agrovets, private sector actors, or NGOs for more information.

Backcast 3: Adequate water for irrigation

The group identified all potential sources of water: groundwater (natural springs and boreholes), rainwater, and river water (Rohini and Tinau Rivers). Beora is already connected to the Tinau River via a canal system, but receives limited water due to upstream users. The participants suggested there would need to be efforts to expand its carrying capacity and frequent community working days to clean the canal. Other sources are essential, groundwater being most appealing.

Beora Borehole Group (BBG) was formed to manage a collective borehole irrigation system. An engineer from the Ministry of Land Reform and Management would be solicited to map current and planned borehole locations as to maximise efficiency of the whole system. Pumps would be needed to extract the water from the boreholes and the existing network of feeder canals will be used to distribute the extracted water. Sustainable methods of pumping will be explored. Afforestation efforts are to be conducted in parallel to help regulate rainwater in the long term.

6.4.2. Participant Selection

The timing of the exchanges, in the lead-up to the rainy season, proved a challenge. Rather than competition for participation, the team found they had to visit each individual household and elicit participation. Almost all villagers expressed a desire to attend the exchanges yet lack of time and concern about the need to prepare for, and begin to plant rice as soon as the first rain began, were limiting factors for participation. Considerable effort was expended to have gender balance on each exchange.

6.4.3. Analogue Scoping Trip and Exchange Site Selection

An illustrative climate analogue map is shown in Figure 6.6. The red areas on the map represent areaswhich currently experience Beora's plausible future climate according to the CAT. The CAT generated multiple such maps in order to take into account climate uncertainties. These maps were used as the basis for the scoping mission to find 3 diverse, yet socially and culturally exchange locations.

Based on the results of the scoping mission throughout the analogue maps, three highly diverse locations were chosen: Madheye Nagar, Chutara and Durua, shown as EX1, EX2 and EX 3 respectively on Figure 6.6. These locations displayed very different social, cultural, physical and natural conditions from one another and were compatible with the reference site. Furthermore, each site featured some aspects which the reference site had identified they were interested in learning, such as water management, agro forestry and integrated pest management.

The scoping mission throughout the analogue map areas demonstrated that local effects such as topography, tree cover, proximity to water bodies, cloud cover and aspect have a significant impact on the climate experienced by a particular community. Scaled down GCMs do not capture these effects and, as such, they are not represented in the analogue tool. Such local effects can be more significant than the impact of global patterns captured in the GCMs. Furthermore, there is enormous variability in these factors within a single grid cell of the CAT. Thus, for a particular village, the results of the CAT for the grid-cell in which the village is located may not be representative for that village.

Figure 6.6. Illustrative Climate Analogue Map - Temperature Analogues.

6.4.4. Exchange Training

Most Significant Change narratives covered issues across sectors, scales and levels: the war with the Maoists ended, changing land tenure and community governance structures; a road to the village increased access to goods, services and livelihood opportunities; a bridge over the river increased access to schools for children and subsequently freed women to gain alternative forms of employment; one woman became a tailor; the climate has been getting hotter and drier leading to changes in crop varieties and timing of agricultural activities as well as increases in health issues, which in turn have affected productivity and livelihoods. Discussion of these interconnected types of change across sectors, scales and levels facilitated understanding of interdependence and contextualised climate change as one of many types (and speeds) of change facing the community.

The villagers were well aware that their patterns of rainfall, stream flows and temperature are changing. Beora used to experience 3 longer seasons and now experiences 5 shorter seasons during which the extremes of temperature and precipitation are worse.

Exchange participants prioritised rice production as the climate-sensitive process they would focus on for decision analysis. The process of mapping out rice production allowed us to facilitate discussion of uncertainty in extant climate information sources, and the information provided by the CAT was situated within these sources and uncertainties.

Critical-thinking training used the recurrent statement, 'development means increased industrialisation and physical infrastructure'. The believing game produced items such as 'tractors increase productivity' and 'factories increase employment'. During the doubting game counterparts were listed: 'tractors contribute to climate change and other pollution', 'working in factories is awful', plus new items. Participants reflected on how both sides held truth and embraced richer, more complex understandings. Whether or not 'factories increase employment' depends on how 'employment' is defined. Through the defining game, participants learned that the truth of statements depends on the definition of key terms, a skill they reported was very useful during exchanges.

6.4.5. Exchanges

6.4.5.1. Exchange 1: Madheye Nagar, Dang District

The first exchange was conducted from June 14–17, 2012, to Madheye Nagar. The exchange site is located in the centre of the Deukhuri Valley with the Rapti River to the south, a community forest to the west and the Syaru River to the east. The community has lived there for many generations, evolving a complex system of agro-cultural traditions including terracing, precision irrigation, intercropping, vegetable farming and silviculture. They have established community savings groups, organised community events and festivals, and conducted training including installation of biogas plants.

Other adaptation initiatives visited included: diverse vegetable farming (deemed as a 'potato pocket area') as an alternative or complement to rice and wheat cultivation in response to increasing drying conditions; off-season vegetable selling at high market value in the neighbouring town of Lamahi; three-phase kalami method of rice cultivation, which enhances production and reduces inputs; conservation agriculture methods; small-scale private fish farming with herbivorous varieties such as grass carp; harvesting of medicinal plants; electric irrigation pumps, and tube wells used for drinking water; small-scale reforestation.

6.4.5.2. Exchange 2: Chutara, Chitwan District

The second exchange took place from June 28–July 1, 2013, in Chutara, Madi Valley, Chitwan district. Madi Valley is a unique location in that it is a buffer zone surrounded by two nature conservation areas – the Chitwan National Park and Valmiki Tiger Reserve, as well as a number of community forests. The valley is also used as a transit point to the Indian border.

People in Chutara experience floods annually and have two rice cultivation seasons rather than one. Being located on the boundary of the reserve, means residents experience wildlife conflict with rhinos and elephants consuming crops, restricted access to harvest fuel wood, and flooding of dwellings along the banks of the Rewu River. These aspects are specific to this location and are not considered plausible aspects of the future of Beora.

Adaptation options seen in Chutara included vermi-composting, biopesticides, development of women's groups, loans and savings schemes, local seed varieties, improved animal husbandry, vegetable farming, conservation agriculture, soil conservation and silviculture. There are nine women's groups in the community conducting education on family planning and maternal health, caring for marginalized members and non-group members through volunteer work and donations, income-generating activities to raise school fees, and a loans and savings scheme. They spoke passionately about how membership with the group has increased their confidence, standing within the household and the community, and the perception of themselves as agents of change and their autonomy.

6.4.5.3. Exchange 3: Durua, Kanjiwar Dang District

The third exchange took place July 19-22, 2013, in Durua, which is a settlement located along the Babai River in the Dang district. This community demonstrates high levels of social organisation with many active committees and elected leadership positions including an agricultural co-op, an electricity consumers' group, a women's development group, several savings groups, a veterans' group and a community- forest-user group. There are several examples of members of the community organizing themselves to address scarcities, lobbying relevant government authorities and designing interventions that uniquely fit their needs.

Adaptation examples included diversification into vegetable farming; three-phase kalami method of rice cultivation; conservation agriculture methods; electric irrigation pumps; canal construction and maintenance; user rotation schemes for irrigation; tube wells for drinking water; developing contingency funds for repair and maintenance of infrastructure including electrical equipment; electricity access advocacy; participatory processes for producing community plans; development of an agricultural cooperative (female-led); promotion of local seed varieties; mushroom production; individual and communal fish farming; a few examples of biogas; operation of a communal rice mill; large-scale reforestation; planting of medicinal trees; tree sapling production, and productive uses of marginal lands.

6.4.5.4. Monitoring and Review conducted throughout the Exchange

Monitoring and review conducted throughout the exchange revealed that the exchange met participant expectations and further:

- Each of the participants identified new adaptations they had observed, which they would like to replicate or not, of both an individual nature (a behaviour change) and of a group nature (larger scale initiatives or interventions based on community organising).
- Cultural displays and entertainment were well appreciated (for example, evening dancing, observing new dress and hearing new dialects).
- All participants were keen to share their experience with others, once returning.
- Many mentioned the idea of social cohesion.
- Many mentioned funny stories or salient experiences.

6.4.6. Post-exchange Scenarios Exercise

6.4.6.1. Similarities and Differences Exercise

Reflection on similarities and differences in each exchange location is demonstrated in Figure 6.7. The scenario extracted from the exchange is experiential. It consists of all of the aspects of the exchange experienced by participants without the incommensurable differences. A list of incommensurable differences for each field site is given below:

- Exchange 1: Within 1 km of a major river, leading to alternative irrigation strategies and a broader variety of cropping options.
- Exchange 2: Human wildlife conflict exists due to borders with protected areas.
- Exchange 3: Different topography, significantly hillier. Within 2 km of large river, leading to alternative irrigation strategies and broader variety of cropping options. History of exposure and adaptation to floods.

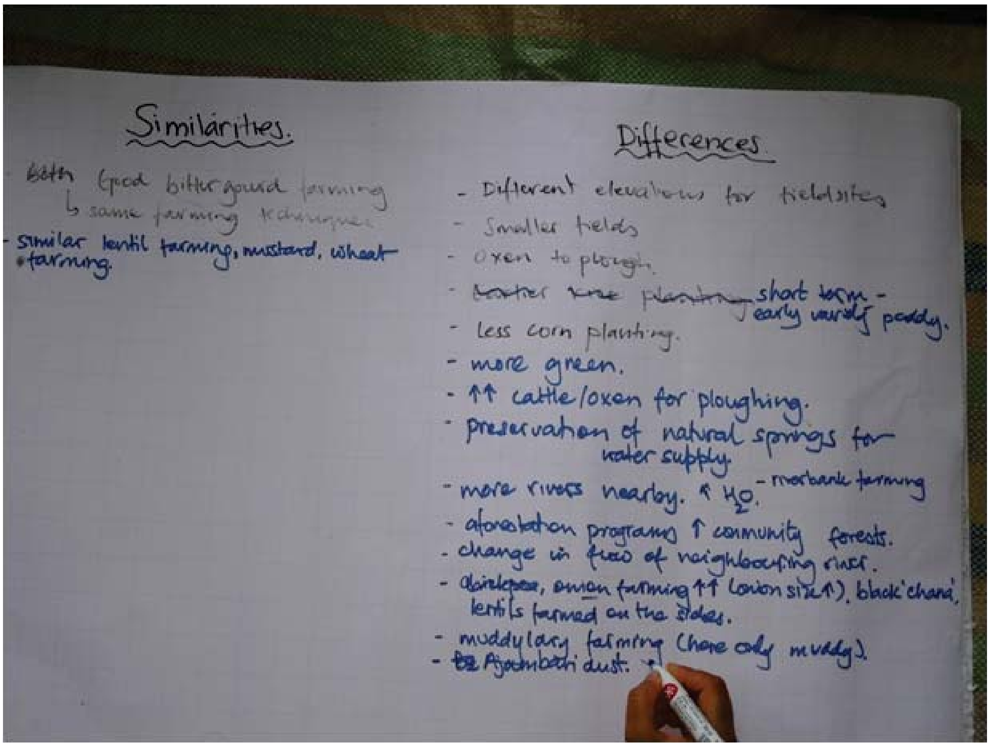


Figure 6.7. Similarities and Differences Exercise.

Following each exchange, all photographs taken by exchange participants with flip cameras were printed. Participants chose which photos best represented the scenario they were creating and made a photo-board/collage to aid visualisation when working through the subsequent backcast revisions. An example photo-board is shown in Figure 6.8.

Figure 6.8. Exchange scenario photo-board.

6.4.6.2. Revised Backcasts

Across all contextual scenarios the normative goals of 'improved agricultural productivity', 'improved soil quality and pest management' and 'adequate water for irrigation' remained the top priorities, even though participants were given the opportunity to revise these priorities. Thus the original backcasts were revisited in the context of each scenario. Figure 6.9 shows the original backcast on the left-hand side and the process of revising it on the right-hand side. Post-it notes were used to add new options or steps, markers used to cross out steps which had become undesirable or redundant and to draw arrows between consecutive items.

Figure 6.9. Revising backcasted plans with each scenario after each exchange, scenario photo-boards visible under backcasting sheets.

The comparison between the original and revised backcasts provided a measure of the changes in thinking, which became possible following the exchange-scenario exercises. In all cases, participants were open to many more actions and action pathways to achieve desired outcomes. This process demonstrates that the exchange-scenario exercise was effective at producing changes in thinking, in breaking down preconceived ideas about the future and opening the minds of participants to new possibilities about their futures.

Backcasts 1 and 2 were amended to incorporate community forestry, particularly woodlot development. The woodlot increases the availability of building materials to construct zero-grazing pens for goats and cattle, where manure for organic fertilizer can be collected. Organic material collected from the woodlot also serves as a source of fodder for livestock. In addition, farmer-based organization development was reinforced in all plans as a result of the strong group culture found in Chutara as a means to promote land consolidation and group vegetable/grass farming.

Backcast 3 was amended to consider the increased rainfall availability during summer months. Although it was envisioned that groundwater extraction would still be necessary, the adaptation involved reduced emphasis on the construction of boreholes, and more emphasis placed on surface water irrigation including canal development and maintenance in the future climate scenario. This included the planting of bamboo along canals to prevent erosion and maintain canal integrity.

6.4.7. Village-wide Dissemination and Planning

Following presentation by all three groups, comparison between all three sets of revisions was possible. Discussion was facilitated around the observation that each scenario provides different opportunities to capitalize on and different barriers to overcome, as shown in Figure 6.1. After this discussion, participant Janaki Chaudhury remarked, 'While we do not know exactly how the future will be, there are many things we can do which will build our capacity to cope with change'(Ademiluyi, 2013). It was determined that the seed money be channelled through Friends Service Council Nepal – a local NGO the community has an on-going relationship with. The actions prioritized were Integrated Pest Management, communal village cleaning and canal maintenance, development of the communal borehole system, improved sanitation, and a community vegetable-growing scheme.

6.5. Handover to Local Partners OneYear Post-program Evaluation

In July 2013, members of the team returned to Beora to conduct an evaluation of the program after one year. The overall evaluation was that the program was very beneficial. According to Kalam Bahadur, 'People have gone out and seen different things, different works, and based on that they can imagine different things and they want to change things, because of the concepts are changing…The program made people imagine what might happen because of our own activities so that motivated people for lots of changes' (sic).

One key benefit is improved capacity for community organizing. Various groups are now functioning, including the group vegetable cooperative called Garima Farmers' Cooperative. Garima Farmers' cooperative organised to gain skills in Integrated Pest Management (IPM) through a ten-week program facilitated with funds provided by the FOTF seed funding. Funds were also used to procure tools including pumps for a community-group vegetable farm on communal land. Participants reported a clear understanding of the FOTF aims and objectives, as described by community leader, Lakshmi Chaudhury: 'The aim of the programme was to support education about changes in climate, in environment as well as social changes and how to plan for them'.

Moreover, community-to-community knowledge exchanges to share best practices have taken place, as members of the community who were not able to take place in the exchanges directly are heavily involved in the activities resulting from the program, and there is recognition in the broader community of the lessons learned through the program.

A number of women indicated an increased confidence and status within the community and both men and women have got a stronger sense of responsibility to contribute to the development of Beora. Women attribute this to seeing other women's groups in the exchange locations and being encouraged to actively participate in FOTF. They reported empowerment through the opportunity for training/education. Anita Chaudhury, a woman who did not directly participate in the program reports,'Women are more conscious of their rights and what they should achieve from society and family. I heard from people who went on the exchange that in those places women are very forward, they talk and they have formed groups and they have developed much within themselves and I got the impression that we should also try to be like them… this program has brought a shift in peoples concept, especially the female group of this community to do something. I myself now have the confidence that I can study further, I can continue my study which was left behind.'

Ongoing support of partner organisations in Beora requires project-based funding. Unfortunately, the seed funding was not used to gain further project-based funding but to partially fund a number of initiatives as mentioned above. This meant that, over time, without funding or support, a number of larger initiatives which required further funding other than the seed funding, including a sanitation program and the collective borehole program, have stalled. More support was needed to develop fundraising and partnership capacity in the community, which was initially unfamiliar with approaches to lobbying for project funding and partnerships.

6.6. Discussion and Conclusions

The 2012 Nepal Farms of the Future program successfully implemented a methodology for building the resilience of the community to climate change through improved understanding of future climate uncertainties, increased openness and knowledge sharing. The methodology included a novel participatory approach to extracting capacity for decision-making under uncertainty and extracting exploratory future scenarios from farmer exchanges to diverse present locations. Both the exchanges and the scenarios exercise were effective and beneficial for the farmers in terms of building adaptive capacity. Farmer exchanges facilitate farmer-to-farmer knowledge sharing, which is an effective and empowering form of horizontal capacity building. Scenario exercises are an effective way of breaking down assumptions about the future that hinder adaptive capacity and building ability to cope with uncertainty and change. Programs such as this have the potential to increase adaptive capacity more than purely technology-focused intervention ever could, by arming farmers with the skills they need to embrace an uncertain future with openness and readiness. The results of the pilot provide insights for appropriate use of the CAT, for farmer exchange programs and for resilience in general.

6.6.1. Considerations for Responsible Use of CCAFS CAT

The Climate Analogue Tool cannot currently be interpreted as providing predictions of how the future climate will be for the following reasons:

- Local effects such as topography, tree cover, proximity to water bodies, cloud cover and aspect have a significant impact on the climate experienced by a particular community. Scaled-down global climate models (GCMs), do not capture these effects. Such local effects can be more significant than the impact of global patterns captured in the GCMs.
- There is large variability in these factors within a single grid-cell of the Climate Analogue Tool. Thus, for a particular village, the results of the Analogue tool for the grid-cell, in which the village is located, may not be representative for that village.
- In all likelihood, the future will not be as the models predict, for a host of reasons, including, due to model uncertainty, parameter uncertainty and the fact that the models are based on sets of assumptions about the future, including emissions trajectories which depend on human behavior globally and locally (IPCC AR4 SYR, 2007).

Framing CAT-based farmer exchanges as 'showing farmers their future', or treating the CAT as a predictive device, is not recommended due to limitations of the tool described above. Indeed, the most responsible way to use the CAT in its current form is to provide sets of 'plausible' climate futures. Thus, an analogue site can be treated as a "plausible" climate scenario. Accordingly, this chapter presents a framework for treating the farmer exchanges to climate analogue locations as an exploratory scenarios exercise. The term, 'exploratory', is used to refer to scenarios which explore what could plausibly happen, rather than describe what will probably happen, or what we want to happen (Börjeson et al., 2006). Thus, various adaptation actions can be stress-tested in a diverse range of exploratory scenarios and the exercise can be used to build capacity for planning and decision-making under uncertainty.

6.6.2. Implications for Farmer Exchanges Based on the CAT

CCAFS CAT calculates analogue locations on the basis of temperature and rainfall. It does not currently take into account any biophysical, ecological, social, cultural, economic, or political factors, and there are practical limitations on data availability and feasibility of including such factors in a model. All of these factors can play a critical role in determining whether or not particular adaptation strategies are feasible in a given location. Socially and culturally, 50 km from a reference site can mean a different tribe or ethnicity with different cultural norms around food, farming, representation and decision-making in the village. For example, this pilot program showed that forming women's groups to implement various forms of livelihood diversification and agricultural training works well for Tharu communities, but would not work for the Yadav people, who do not permit women to belong to any groups. Economically, while garlic may be grown in the exchange location and theoretically be an environmentally and socially appropriate adaptation, if there is no market access for garlic in the reference site, this will not work. Biophysical factors such as soil types play a major role in the success or failure of certain crops. Thus, particular thought must be given to choosing socially, culturally, economically, politically, biophysically and ecologically appropriate exchange locations.

Also, in spite of the power of the metaphor, and the science behind it, we are not actually achieving time travel. We are taking farmers to a different present location and imagining that aspects of it could plausibly be part of their futures at some point. Since we are dealing with a different location in the present this means that, a) there will always be some incommensurable differences, many of which may not be completely obvious until the exchange is taking place, between the reference and exchange sites due to their being different locations on Earth; and b) farmers will not see futuristic technologies, infrastructure or approaches which have not yet been developed in the present; other deeper social changes that can take generations, such as changes in gender norms around education and participation in decision-making, caste structural relationships and broader governance structures, are difficult to find examples of.

Finding futuristic scenario exchange locations can be hard to achieve without travelling a significant distance, by which time other social and cultural barriers, including language and the ability of farmers to communicate with one another, can become factors in whether or not the exchange is feasible. A balance is needed between commensurability of various social, cultural, economic and political features of the exchange site and the initial site as well as the potential of farmers to learn from different tools, techniques and approaches in the exchange site.

Balancing the requirements of cultural appropriateness, with the objective of maximizing how much participants can learn and explore, suggests that the concept of exchanges to climate-smart display villages nearby could be a good idea. Note that visiting a single display village represents one normative scenario, based on the values of those who designed the display, and does not provide the opportunity for the participants to explore alternative plausible futures. Careful preparation would be required to cope with differences in participant visions, values and aspirations with the visions, values and aspirations of those involved in designing the display village. Furthermore, while a display village might allow villagers to learn more specific techniques and technologies, it is difficult to create display villages which model the social, cultural, organizational and political aspects required for adaptive capacity.

These considerations do not lessen the utility of the tool, but imply important methodological considerations for its use. These include incorporation of:

- Exercises exploring the nature of change facing the community, past, present and future; combined with exercises exploring the uncertain nature of these changes and methods of coping with this uncertainty extant within the community. Changes relating to climate are included as one of a number of relevant types of change for the community. The notion of a multitude of divergent possibilities for the future, the role of agency and its limitations are also explored.

- Exercises exploring the use of uncertain information for decision-making. Use of the CAT results with the community must be situated within sources of information currently used by the community to ensure it is not interpreted as superseding everything they already knew, due to its technologically impressive appearance. Include exercises that clarify the limitations of the CAT and what it can be used for together with the rest of their knowledge about climate.

- Sensitivity training about climate change that clarifies the meaning of the exchange program without frightening, and possibly overwhelming, villagers who already face multiple stressors.

6.6.3. Implications for Farmer Exchanges in General

Some of the methodological considerations arising from this program apply to farmer exchanges in general, whether or not they make use of the tool. General principles arising from this program are:

- Exchange locations should be chosen, which are socially, culturally, economically, politically and environmentally appropriate for the participant village. The Diagnostic Workshop can be used effectively to generate a list of criteria under each of these headings for exchange location selection.
- The exchange location selection and program design should be based on alignment with local aspirations, visions for development, capabilities and priorities for intervention. This maximizes absorption and uptake while minimizing the practical and ethical hazards involved in imposing externally generated interventions (Mikkelsen, 2005).
- All exchanges must involve critical-thinking training to ensure that participants are able to discriminate, in an open-minded, receptive and realistic manner, which aspects of the exchange location will translate well in their own environment and which will not, based on a range of social, economic, environmental and political considerations. This should be followed up during and after the exchange.
- Preliminary training is also necessary to ensure participants do not become demoralized about their own realities and given the notion that the places they are being taken are 'more successful'. Exchanges should aim to ensure participants feel empowered to effect positive change in their home. This is done by appropriate framing of the exchanges and preliminary training. The participants should feel that they have chosen to visit the exchange location based on their own requirements, rather than that they are being shown the success of other communities as a direct reflection of their own performance.
- Exchange participant selection should maximize capacity for dissemination of exchange learning to the broader community, rather than creating disparity. Allow the participant community to define the participant criteria that will maximize value to the entire community and suggest participants based on these criteria. Nominations must be cross-checked against different forms of social differentiation, such as gender, age, caste and ethnicity, and seek additional willing participants to ensure equitable representation.
- Ongoing village-level dissemination activities will be required following the exchange. Change takes time– the planning and implementation processes can require support for a period of 6 months to one year or even longer.
- Timing of the exchange program is important. The FOTF pilot occurred in the lead-up to the rainy season, making some farmers wary of being away in case it started raining and they needed to plant rice. The rains had begun by the time the third exchange took place, meaning that rice cultivation was in full swing. These factors prevented some people from participating. Participants highlighted that they would have liked to have more community

members involved in the training, workshops and exchanges.

- Ensure seed funding is used to gain further project funding and build ongoing partnerships, as required for continuing initiatives.

6.6.4. Conclusions

The axioms of building resilience arising from this program can be summarized as follows:

- **Local ownership and leadership matter:** The success or failure of various resilience or adaptation interventions over time relied upon local people having the will, resources and skills to carry them forward.

- **Alignment with local values, visions and aspirations for the future is essential:** No matter how excellent scientists, development practitioners or policymakers consider an intervention to be, if it is not what stakeholders want, they will not have the will or invest the resources and skills required to implement, maintain and live with it. Allowing farmers to identify what matters to them, and to co-develop appropriate solutions to their own problems, eliminates this problem and the issue of 'adoption' in general – it is their plan, they own it, they don't need to adopt it. The community is more open to external input in this context, since it contributes to their own plans, and they have identified the need themselves.

- **Building resilience takes time:** As with any development or change management process, change takes time and ongoing support is required. Being able to see things work in practice is particularly important to people who cannot afford to take too many risks. Furthermore, there will always be some people who change immediately as a result of an intervention such as farmer exchanges, some who wait to see how an adaptation action works for others in their village before trying, and some who are resistant. It takes time for changes to diffuse through a community through observation and trial. Thus the impact of interventions such as this cannot be effectively evaluated simply by counting intervention uptake for perhaps 5 years, by which time attribution becomes problematic. We aimed to capture **changes in thinking** as a result of FOTF as well as capturing adaptation options implemented.

- **Succession planning and ongoing support is essential:** The villagers needed ongoing support even to know how to use the seed funding appropriately. Villagers reported that adaptation attempts that failed or stagnated did so because of lack of consistent ongoing support.

- **Building on existing strengths in the community** rather than relying on leveraging external knowledge and resources, and empowering the community to develop and seek its own self identified solutions, is far more sustainable, particularly in the situation where continuous and ongoing external support is not consistently available.Thus people will ultimately have to rely on themselves. Focusing on leveraging external knowledge and resources fosters dependence and this is a danger of individual technical-intervention-based, time-limited projects, unless they are contextualized as part of a broader, locally owned, ongoing community planning and development process.

- **Learning by doing:** The old adage, 'Tell me and I will forget, show me and I will remember, let me and I will understand' is true for adaptation learning. Thus, farmer-to-farmer learning by example and trial is excellent. Such approaches include farmer exchanges, based on the

CAT, or to climate-smart villages, or farmer field schools, and so forth. Some comments have been made about exchange varieties in Section 5.2.

- **Community organizing is a major source of adaptive capacity for poor rural communities:** Getting together to leverage skills and resources both internally and externally occurs in almost all community adaptation plans. However, minority groups may have restrictions on group membership, such as in the case of the Yadav in Beora. Also, communities have different degrees of capacity to organize themselves and may require ongoing support, utilizing the convening capacity of outsiders for that purpose.

- Working with agricultural communities to facilitate **resilience involves shared and reversed learning:** the community teaches us about its needs, about what will work, what won't, and why. Accordingly, it is important to:

- **Acknowledge different forms of knowledge, including local and traditional knowledge and different ways of obtaining knowledge** in the success of any adaptation intervention.

- **Each community is unique and options that work in one place may not work in another, even very close by,** and even when many control variables are aligned. Thus, co-developing resilient pathways together with communities, based on local strengths and drawing on suites of flexible adaptation options that can be tailored by communities themselves to their particular needs, can be helpful.

7.

Measuring Resilience

7. Measuring Resilience

7.1. Introduction

The operational framework presented in Chapter 5 applies to the quantification of resilience. Modelling involves specification of the boundaries of the system being modelled, which variables will be included in the model and which will be left out. These choices are also influenced by the types of disturbances of interest since the model must be capable of capturing the impact of the disturbance and calculate the response of the system. In order to quantify the response of the system to the disturbances of interest, this second point also means we need a quantitative model of how the variables of the system relate to each other to allow us to calculate the response to disturbance. We also need a quantitative measure of desirability over the state space so that we can classify whether the response of the system to disturbance was able to preserve or improve desirable features of the system. Quantifying the response of the system to disturbance depends on the time frame, since a change that seems initially negative may turn out positive later, and vice versa. Thus, we need to specify of what, to what, from whose perspective, and over what time frame.

As discussed in Chapters 4 and 5, the answers to these key framing questions are not given objectively but depend on the values, priorities and world views of those involved in the modelling process. Modelling the resilience of human and natural systems is therefore a highly complex multi-actor process involving social, economic, political and biophysical dimensions across diverse scales. There is a need to integrate knowledge across disciplines, sectors and social worlds, involving diverse stakeholders and experts, since each has only partial knowledge about the various aspects of the system relevant to any particular topic (Gibbons et al., 1994, Ulrich, 1993). Furthermore, different actors have different world views, values, visions and aspirations, and beliefs about the actions required to achieve 'positive' outcomes from their perspective (Ulrich, 1987), and these notions determine what is interpreted as resilience or adaptation versus vulnerability or collapse.

According to the operational framework, the quantitative modelling process should itself be transparent to affected stakeholders; they should be part of the process and able to interrogate it. There is both a moral and a practical need to integrate scientific and expert knowledge with the knowledge and perspectives of lay stakeholders whose lives will be affected by any intervention to inform design of effective policies and actions (Hammond et al., 1999). Involvement of affected stakeholders is an ethical requirement and, in many social and environmental situations, public involvement is mandated by law (Ozesmi and Ozesmi, 2004, Ulrich, 1983). Those stakeholders, who will have to implement, maintain and live with any intervention, can determine its success or failure according to their level of buy-in (Mikkelsen, 2005). Further, the grounded knowledge they possess, often not captured in scientific and expert knowledge bases, provides insights which support more innovative and appropriate design of policies and actions (Midgley and Richardson, 2007).

Fuzzy Cognitive Mapping is a technique for modelling complex real world situations, capable of integrating knowledge from multiple actors, disciplines and sectors, including the public (Kosko, 1986, Kosko, 1988, Stach et al., 2010) . Fuzzy Cognitive Maps (FCM) can handle both qualitative and quantitative inputs and outputs, and can be used to bridge the divide between qualitative and quantitative analyses of a situation (Kok, 2009, van Vliet et al., 2010). They can be used to represent different mental models of how the world works, and draw various conclusions about belief systems and value systems of different individuals and groups (Gray et al., 2014). This can provide the basis for building shared understanding and clear grounds for negotiation when there is a difference of opinion about what is going on and what should be done to address particular issues in global environmental change (Vaidianu et al., 2014, Wildenberg et al., 2014). As such, they provide a powerful basis for effective stakeholder engagement, providing a common language and representational form for different actors to make sense of complex situations involving multiple perspectives and values, and qualitative and quantitative knowledge bases.

For these reasons, FCMs have gained significant popularity across a range of fields of application over the last decade. They have been applied to environmental management, agricultural systems, education, political science, social science, psychology and behavioural science, medicine, engineering, robotics, information technology and telecommunications, business and management (Glykas, 2010, Papageorgiou, 2014). In particular, in recent years, there has been an order of magnitude increase in the number of FCM studies and papers published on theory, methodology and applications (Papageorgiou and Salmeron, 2013) including two books devoted to the topic (see Glykas 2010 and Papageorgiou, 2014).

Accordingly, the author saw FCM as an appropriate modelling approach, to quantifying resilience in terms of whether the response of the system to disturbance is considered as maintaining or improving on desirable features of the system. Investigation, including field trials, of the potential of FCM for modelling resilience revealed that there are still serious discrepancies in literature and practice about what constitutes appropriate application of the method, what types of models the FCM methodology produces and how they should be interpreted. For example, within the literature, reference can be found to FCM in terms of three types of mathematical models: fuzzy causal reasoning, neural networks and system dynamics models (Stylios and Groumpos, 1999, Stylios and Groumpos, 2004). In this chapter, we first resolve methodological discrepancies in the literature and explain how each of these models work, how they are related and how they are not. In the process, we describe some common traps, found in the literature involving the application of these models under the banner of FCM, that have significant implications for inferences made for decision-making. Based on insights into these areas, we provide guidelines for the simple, coherent and effective use of FCM and related techniques for social and environmental decision-aiding processes. Further, we apply the framework for quantitative measurement of resilience to an FCM in order to illustrate how resilience can be measured.

The claim of this chapter is that internal coherence of the mathematical formulation of FCM activities with conceptual interpretation is important for the quality of the results and the meaning derived from the participatory and analytical exercises that generated the FCMs. Further, we believe disambiguating this information has significant implications for the nature of stakeholder engagement activities and the clarity and simplicity with which they can be facilitated. The material in this chapter has already proven useful for practitioners of FCM in a number of EU FP7 programs including ROBIN and TRANSMANGO (ROBIN, 2014, TRANSMANGO, 2014).

Before we can model resilience, it is necessary to provide conceptual and mathematical clarity on the topic of FCMs. Given the proliferation of FCM-based studies and programs, the significance of the decisions they are being used to aid, and potential for a degree of perplexity, this is an important and timely contribution. Having provided this clarity, this chapter then uses a simple model of socio-ecological food system to illustrate the quantitative measurement of resilience.

7.2. Cognitive Maps and Causal Reasoning

A cognitive map is a visual representation of how a system works from the perspective of those who constructed it. The form of a cognitive map is a directed graph, where nodes represent particular concepts and links represent perceived causal relationships between concepts (Axelrod, 1976). These concepts are variable concepts, things that can be caused or not. Kosko gives the example of the model representing social instability, rather than society itself, which can be caused or not, and can cause other things or not, whereas society cannot (Kosko, 1986). The variable concepts can be measurable quantities, such as temperature or population, or abstract concepts (more difficult to directly quantify), such as trust or political will. The values of the variables themselves are not quantified in a cognitive mapping process so it does not matter if they are quantifiable or not.

In participatory processes, cognitive maps are frequently constructed according to the following stages (Ozesmi and Ozesmi, 2004). Firstly, the individual or group constructing the map brainstorms all of the factors that are relevant to a topic of interest. The relevant factors are worded as variable concepts that can be caused and can exert causation, and are written on cards. The participant(s) then organize the cards into a logical structure and draw lines between the concepts to indicate where they believe there is a causal relationship between the concepts represented. The direction of the arrow indicates that the concept at the base of the arrow, when it exists, causes the concept at the head of the arrow to happen. In this way, participants produce a directed graph. An example directed graph is shown below.

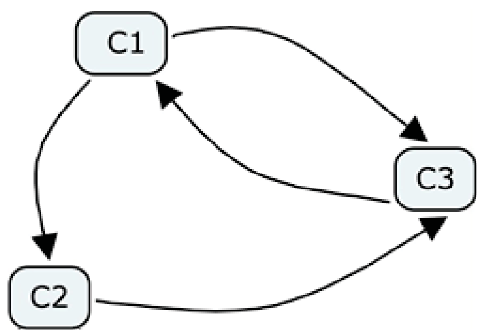


Figure 7.1. Example Unsigned Cognitive Map.

This initial model-building stage is extremely useful in participatory processes and is extremely flexible, as participants identify and determine which social, economic, political, physical and ecological aspects of the world are relevant and should be included in analysis of the issue and which can be left out. The decisions about how to bound the system being modelled, known as 'whole system judgements' are subjective and vary by participant(s) (Ulrich, 1983). The way different participants or groups draw the links represent different mental models and belief structures about how the world works and suggest different modes of addressing any given issue (Gray et al. 2014). Given a particular topic, such as deforestation in the Amazon, or management of European water resources, different stakeholders will advocate for the inclusion of different system elements, perceive different relationships between these elements and advocate for different actions, based on their spheres of concern and knowledge. Making these different world views explicit through the selection of elements and the linking process, and appropriately negotiating the world view(s) which will be taken forward in further analysis, is key to ethical and effective policy and program development (Ulrich, 1987, Midgley, 2000).

Relationships between concepts, represented by arrows in a cognitive map indicate that a particular concept causes another concept. The next phase of the participatory process involves participant(s) adding signs to the cognitive map. A '+' is placed on a link between A and B if 'A causally increases B', meaning that the participants believe that A happening directly causes B to happen, or increases the causation of B, or has positive causation. A '-' is placed on a link between A and B if 'A causally decreases B', meaning that the participants think that A happening directly causes B not to happen, or decreases the causation of B, or has negative causation. If there is no link between A and B, A does not directly causally affect B, meaning that A happening does not directly cause B to happen or exclude it from happening (Kosko, 1986, Kosko, 1988). The variable concepts in this model can be in one of two states, caused or not caused, happening or not happening, often referred to as 'active' denoted by 1, or 'not active' denoted by 0.

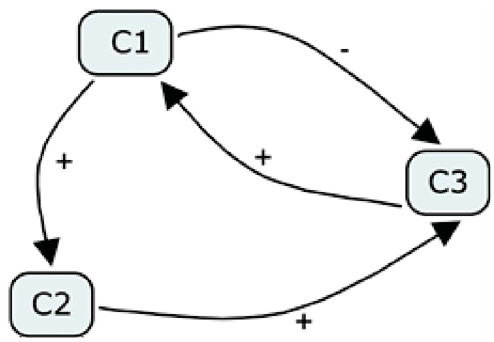


Figure 7.2. Example Signed Cognitive Map.

The term 'directly' is important and underlies one of the values of cognitive mapping. In Figure 7.2, the participants do not believe that C2 directly causes C1; however, by mapping the concepts, they discover that they believe that C2 happening causes C1 to happen through a chain of causation. Given specification of certain concepts happening/active, we can trace the flow of causal reasoning in the map by tracing the arrows to work out the state of the other variables, that is, whether they are happening (caused) or not happening (not caused). This is the proposed value in cognitive mapping, knowing, or assuming, some initial set of things are happening; causal reasoning provides one answer to what other desirable or undesirable things may happen through the chain of causation, a chain that might not readily be discernible without the mapping.

It is important to clarify that cognitive maps deal with chains of causation rather than chains of effect, though the two are obviously related. In this type of model, the state of the variable is not the value of the variable. This type of model tells you whether something is caused to happen or not (cause), it does not tell you the value of the variable, or how its magnitude is changed, due to changes in the magnitude of other variables (effects).

In a participatory process, this is a place where there is potential for different interpretations that require clarification. Cause and effect are often used as proxies for each other. We can think something causes something else because we have observed some effect. The sentences, 'A causally increases B' and 'A causally decreases B', in both Axelrod and Kosko's original presentation of cognitive mapping could be understood by readers to mean 'an increase in the value of A causes an increase in the value of B' and 'a decrease in the value of A causes a decrease in the value of B' respectively (Axelrod, 1976, Kosko, 1986). This phrasing is in terms of effects on the value of the variable. In fact, in isolation, positive causality is accompanied by positive effect and negative causality is accompanied by negative effect, so this is a reasonable proxy to establish direction of causation. However, it is potentially a dangerous proxy to use as it can pre-frame practitioners and participants to think they are modelling changes in the values of the variables themselves, when in fact cognitive maps model flows of causation. This point is ultimately very important for subsequent analysis, since cause and effect have different mathematical models. Cognitive maps, and fuzzy cognitive maps as an extension of cognitive mapping that allows ambiguity in causation, are devices for causal reasoning.

Cognitive maps were not the first devices for mapping causal reasoning. Pathway Analysis in statistics was developed around 1920 (Wright, 1921) and has many graphical and Bayesian progeny, but the simplicity of cognitive mapping makes it attractive for participatory techniques. Cognitive maps can also be constructed from document analyses as well as in participatory processes. Axelrod and Kosko give numerous examples, including a Cognitive Map of Middle East conflict constructed from Henry Kissinger's documents (Kosko, 1986).

However, causation is a difficult concept; it is somewhat of a philosophical minefield (Mackie, 1980, Lewis, 1973, Broadbent, 2012) and, in the binary notion of 'caused or not caused', we can already observe numerous difficulties in cognitive mapping. In Figure 7.2, we see that participants believe that C1 happening causes both C3 to happen (through causing C2 to happen) and excludes C3 from happening. Whether C3 happens or not, given that C1 is happening, is ambiguous and our ability to casually reason using this cognitive map is limited. Axelrod (1976) termed the causal relationship between C1 and C3 indeterminate, and one can take the simple algebra he developed no further when indeterminacy is present (Axelrod, 1976).

Axelrod also introduced the use of the adjacency matrix A for analysis of cognitive maps. The ij^{th} element a_{ij} of the adjacency matrix **A** gives the value on the link between concept i and concept j, which is either -1, 0 or 1 where -1 represents causal decrease, 0 represents no causal relationship and 1 represents causal increase. The adjacency matrix **A**, for the example cognitive map in Figure 7.2, is given in Equation 1.

$$A = \begin{bmatrix} 0 & 1 & -1 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix} \qquad (1)$$

The usual graph theory measure of centrality of a node in a cognitive map is called the 'causal conceptual centrality'. Various graph theoretic measures and their interpretation for environmental decision-making are covered well by Ozesmi and Ozesmi (Ozesmi and Ozesmi, 2004).

7.3. Fuzzy Cognitive Maps and Causal Reasoning

Kosko explored fuzziness as 'an alternative to randomness for describing uncertainty' (Kosko, 1990) (p. 211). A Fuzzy Cognitive Map (FCM) is a cognitive map modified to capture uncertainty in causal relationships. 'Their fuzziness allows hazy degrees of causality between hazy causal objects (concepts)' (Kosko, 1986) (p. 65). Where a link exists in a cognitive map, there is no doubt that the causal relationship does always exist, and in the absence of conflicting inputs to a node – indeterminacy – states are certainly "active" or "inactive". According to Kosko, 'cognitive maps are too binding for knowledge base building. For in general, causality is fuzzy [...] It occurs partially, sometimes, very little, usually, more or less, etc.' (Kosko, 1986) (p. 67).

Fuzziness provides a resolution for indeterminacy, for, if you were 'certain' C1 causes C2, 'certain' C2 causes C3, and you were 'certain' C1 excludes C3, then something is wrong and only your certainty about these relationships can give way. There is some merit in using fuzzy cognitive maps to interpret '+' and '-' pathways that lead into a concept as opposing causal forces. With careful interpretation and for the right concepts, in some cases, 'more' caused should win over 'less' not caused resulting in, say, the forces aggregating on the side of a caused state. The resolution of indeterminacy enables a form of causal reasoning (Kosko, 1990).

As an example, consider asking your child to clean her room. Asking your child to clean her room does not certainly cause the room to be clean, though it does some of the time, to some extent. After you ask your child to clean her room, she may or may not clean it. In the case that she does clean it, did you cause that? The answer is 'well, kind of... to a degree'. Perhaps you think that, if you didn't ask her, she probably wouldn't have done it at all so, in some way, you contributed to it being clean by asking, though you did not fully cause it. The child is not a robot; no matter what constraints you put on a child to behave in particular ways, you cannot fully cause their behavior.

Now introduce her favourite television program. In the absence of your asking, watching the television would almost always prevent the room being cleaned. Usually, in the absence of the television, your asking would mostly cause the room to be cleaned but, in competition with the television causing the room not to be cleaned, overall your asking loses out against the television. The room, though it could end up being cleaned or not cleaned, leans toward the not cleaned state. In the original sense of fuzzy sets, we would say that the state of the room (which is uncertain/ambiguous because your asking does not always cause it to be cleaned, and there is a competition of causal forces) belongs more to the not-cleaned state than the cleaned state. If your asking and television is of equal causal influence, then the state of the room should remain the most ambiguous and belongs equally to the cleaned and not cleaned state.

Fuzzy cognitive maps are fuzzy directed graphs, an involved mathematical concept, but we will describe their simplest mathematical form and how they can be used for causal reasoning in participatory processes.

In FCMs, a link is drawn where a causal link potentially exists, to some degree. A weight between 0 and 1 is placed on the link to capture the degree of uncertainty in the causal relationship. FCMs show haziness in causality rather than haziness in magnitude of effect. The stronger the potential that causation will occur, the closer the weight is to 1, and the weaker the potential that causation will occur, the closer the weight is to 0. If you know your child will certainly clean her room when asked, you would put a 1 on the link between 'asking' and 'clean room'; if you know your child certainly does not listen to you at all, and that there is no link between your asking and the room being cleaned, you would not put a link, which is equivalent to 0 – otherwise you may put something in the interval (0,1). The sign of the causality is established according to the convention described in the previous section, thus ultimately producing a number on the link in the interval [-1,1]. An example FCM is shown in Figure 7.3.

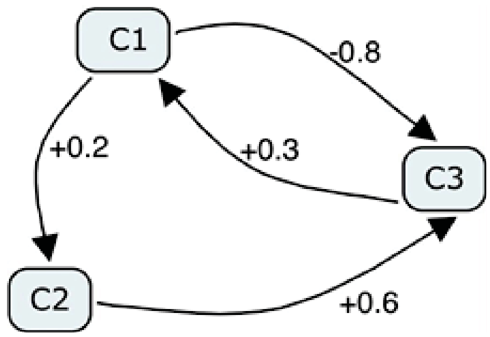


Figure 7.3. Example Fuzzy Cognitive Map.

In the example in Figure 7.3, potentially C1 could be fishing, C2 decline in fish stocks, C3 poverty. FCMs permit feedbacks because it is valid to be uncertain whether one concept causes another or is caused by another, or the direction of causality is ambiguous because the model has not specified time evolution and so it is possible for concepts to cause each other under different conditions and time that the model does not resolve. Ideally, of course, you would include this temporal resolution in more refined conceptual modelling, but it is possible for an FCM to represent the ambiguity. There is no trick or magical gain in this; all that will happen by using an FCM is that you'll get a more ambiguous answer to your analysis, requiring more cautious interpretation, which is potentially more honest for complex real-world decision-aiding.

Stakeholders may tend to estimate the strength of causality by the number of times something happens in response to something else in their experience, that is, using effect as a proxy for causality (Wildenberg et al., 2014). This is potentially dangerous, as it leads to the potential interpretation of the link as the conditional probability of an event given another and, while there is a relationship between fuzziness and probability and they are both ways of dealing with uncertainty, they are not exactly the same thing, and the aim is not to estimate probabilities (Kosko, 1990).

The adjacency matrix **A** of the FCM is defined in the same way as for cognitive maps, so that the element in row i column j, a_{ij}, is equal to the value of the number on the link between concepts i and j and is in [-1,1]. Thus, the adjacency matrix for the FCM in Figure 7.3 is given in Equation 2.

$$A = \begin{bmatrix} 0 & 0.2 & -0.8 \\ 0 & 0 & 0.6 \\ 0.3 & 0 & 0 \end{bmatrix} \qquad (2)$$

The states of the concepts in the cognitive map are also made fuzzy. In cognitive maps, the variables can only have value 0 or 1, meaning caused (active) or not caused (inactive). In FCMs, the state can be caused, not caused, or somewhere hazily in between. The state is specified as a row vector **S**, where S_i is the state of concept i. The states of the concepts is 'fully active': 1, 'active to some degree': in (0,1), or 'not active': 0; not the value of the variable itself. To continue the previous example, we don't know that the room is partially clean and how clean it is (which would be a description of effect), but we are uncertain whether it has been cleaned or not been cleaned.

The FCM can be used to make inferences about causation from any given set of initial conditions. These initial conditions may represent a policy or program intervention that activates particular concepts. Making inferences about what is caused to some degree, and what is not caused by the intervention (according to a particular world view represented by the whole FCM), is based on calculation of how this activation subsequently spreads through the graph.

Let the total direct causal input to node i be T_i. The total direct causal input to node i, at any point during the activation spreading process, is the sum of the active causalities to the node. The active causalities are obtained by multiplying the activation state of each preceding node by the weight that specifies the degree of causal influence it exerts when active. A node that is not active will not exert a causal influence on nodes it is subsequently connected to. Negative and positive causalities act to cancel each other out in this summation.

$$T_i = \sum_{k=1}^{N} S_k \, a_{k,i} \qquad (3)$$

The most T_i could ever be is N, if all N concepts are fully active and exert full positive causality on node i, and –N, if all N concepts are fully active and exert full negative causality on node i. If T_i is 0, then all direct causal forces on the node i are equal, or the node i has no causal connection at all.

The level of direct causal input needs to be transformed into knowledge about whether the concept at i is a degree of 'activated' or 'not activated' as a result. Accordingly, the value of the state is in [0,1], though, in general, the input to the node T_i could be in [-N, N], thus a squeezing function is used. In the simple case where the state is not fuzzy and must be either 1 or 0, that is 'activated' or 'not activated', threshold functions are used. In the case where a concept can be partially active, continuous squeezing functions are used to transform the sum of the inputs to a value between 0 and 1. This squeezing function is known as the activation function, since it is used to calculate the activation level of node i.

The most common activation function used in FCM is the unipolar sigmoid function given by Equation 4, which squashes its content within [0,1]. The slope of the unipolar sigmoid function is defined by the choice of the parameter λ shown below. Its value must be established by the FCM designer. For high values of λ, the sigmoid approximates a discrete function (threshold function), and, for lower values of λ, the sigmoid approximates a linear function, while values of lambda closer to 5 generate a balanced degree of fuzzification of the state (Bueno and Salmeron, 2009). Other squeeze functions used include the hyperbolic tangent.

$$f(x) = \frac{1}{1 + e^{-\lambda . x}} \qquad (4)$$

The choice of the form and parameterization of the squeezing function has been shown to have significant impact on results, sometimes reversing certain conclusions (Papageorgiou and Salmeron, 2013, Knight et al., 2014). This relies on the judgement of the modeller and feedback with participants to adjust, and is a demonstration that robust analytic techniques should be used. Note the important property of most continuous squeezing functions, especially the sigmoid function, that $f(0) = 0.5$. So, if all causal forces on a node cancel out, we get the correct interpretation that the node state caused by these forces is in its greatest degree of ambiguity, that is, belonging equally to the state of 'activated' and 'not activated'. This is the fuzzy logic equivalent of Axelrod's original indeterminacy. It is also the correct interpretation if the node has no causal connections at all, because our knowledge about the activation or deactivation of other disconnecting concepts imparts no knowledge about the state of the node in question, so its state due to causation from the activated concepts could be anything.

Kosko calculates each subsequent value of the state S_i of concept i of the concepts given an initial input by Equation 5 (Kosko, 1988, Stylios and Groumpos, 1999):

$$S_i(j+1)= f(\textstyle\sum_{k=1}^{N} S_k(j).a_{k,i}) \qquad (5)$$

where j denotes the iteration number. For the entire state vector **S**, this is equivalent to the matrix equation given in Equation 6:

$$\mathbf{S}(j+1)=f(\mathbf{S}(j).\mathbf{A}) \qquad (6)$$

An initial activation state **S**(0) will directly cause **S**(1), which will subsequently cause **S**(2) and so forth. To follow the chain of causation through the FCM, we have to repeatedly apply Equation 6.

This calculation rule, the original introduced by Kosko, calculates the state of each concept based only on the influence of interconnected concepts at each moment. This is referred to as a 'memoryless algorithm'. Various authors have suggested introducing memory into the calculation, so that subsequent states depend not only on the sum of active causalities, but also on any (weighted) number of past states. The following equation is the most common and includes the preceding state in the calculation of each subsequent state with weight 1 (Papageorgiou and Salmeron, 2013, Papageorgiou and Salmeron, 2014, Stylios and Groumpos, 2004, Stylios and Groumpos, 1999):

$$S_i(j+1)= f(S_i(j) + \sum_{k=1}^{N} S_k(j)a_{k,i}) \qquad (7)$$

For the entire state vector **S**, the matrix version of this equation is given in Equation 8:

$$\mathbf{S}(j+1)= f(\mathbf{S}(j)+\mathbf{S}(j).\mathbf{A})=f(\mathbf{S}(j)(\mathbf{I}+\mathbf{A})) \qquad (8)$$

Thus, including the previous state in the calculation of the subsequent state (according to Equation 8) can be achieved by putting 1s along the entire diagonal of the adjacency matrix. If weights are used to temper the effect of the previous states, the weight on preceding state i, k_i can be set as a_{ii} (Stylios and Groumpos, 2004).

After repeated calculation of each successive state of the FCM with Equations 6 or 8, most FCMs will settle on either a single stable activation state or a stable recurrent pattern of activated concepts, known as a stable limit cycle. 'In practice it will converge after very few iterations' (Kosko, 1988). This is the inference the FCM provides about causation for a given input. It gives us an uncertain understanding of what will be caused in certain conditions, given uncertain causal relationships.

FCMs can be used to calculate how different world views suggest different inferences about the world. Maps produced by different experts or groups can also be combined to produce a larger representative knowledge base of all of the participants. 'Larger expert sample sizes should produce more reliable knowledge bases… The strong law of large numbers ensures that, as expert sample size increases, knowledge base reliability increases' (Kosko, 1988). Note that this does not mean the individual maps will produce the same result as a combined map, each represents different world views and is likely to give different results, it means that, as the number of experts involved increases, the form of the overall FCM in terms of elements and weights will eventually stabilize and constitute a good representation of the state of extant knowledge on a topic.

Kosko suggests that each expert/group can have a credibility weight w_i in [0,1], representing the degree of certainty we have a priori about their knowledge, which combines well with the overall graph, since an FCM itself represents uncertain knowledge, and thus we can combine uncertain knowledge sources (Kosko, 1988). Combined weighted FCMs can reflect the different levels of expertise on the topic. Of course the quantification of credibility itself reflects particular world views about legitimate sources of expertise and knowledge. In any case, equal weights of 1 could be given where appropriate.

According to Kosko, the method for combining maps is as follows: include all elements of all maps in a larger augmented matrix. The ijth element of the augmented matrix A is the weighted average of all of the entries for that position (0 in the case where the concepts/link did not exist in a particular map) and 'the Kolmogorov strong law of large numbers ensures that, with probability one, as sample size increases, A approaches the underlying matrix distribution of means' (Kosko, 1988). Combining connection matrices is a type of adaptive learning, adjusting the entire FCM as new information comes to light. Changing the elements, links and weights in an FCM is what is referred to when Kosko talks about the dynamics of the FCM. The dynamics of the FCM are not the same as the dynamics of the underlying variables; this will be addressed more in Sections 4 and 5.

In summary, FCMs are a practical way to represent uncertain causal knowledge of different actors individually, or in groups, and the maps produced can be examined in isolation or combined. They can give us a lot of information about differences in how stakeholder knowledge is structured and what this suggests for policy and action (Gray et al., 2014, Ozesmi and Ozesmi, 2004). The results of FCM calculations (the FCM inference) must be used carefully since, as discussed above, these results are sensitive to choice and parameterization of squashing function, the amount of memory the state of the FCM has, and how different maps are combined; without proper sensitivity analysis testing the robustness of the conclusions, there is a risk of using gibberish results or of tweaking the map to produce what you already think or want.

Using FCM, practitioners can examine what will be caused from any given set of initial conditions according to the knowledge represented. This gives an indication of how to steer towards desirable states and avoid undesirable outcomes, thus managing resilience.

7.4. Fuzzy Cognitive Maps and Artificial Neural Networks

FCMs, as described above, are structurally analogous to Artificial Neural Networks (ANNs) (Kosko, 1988, Papageorgiou and Salmeron, 2013, Stylios and Groumpos, 1999). Both FCMs and ANNs are weighted directed graphs where the nodes are activated or not as a function of summation of the input to the node, known as the activation function. The activation function most commonly takes the form of a threshold function or unipolar sigmoidal function in both FCMs and ANNs.

The structure of ANNs is designed to mimic the physiology of the human brain: nodes represent neurons, which can have any number of inbound connections known as dendrites, each neuron has only one outbound connection known as an axon, which can subsequently branch. Thus nodes can have any number of inbound and outbound connections. These connections act to propagate electrochemical stimulation between neurons. If the sum of the inputs to a node/neuron is greater than a threshold, the neuron becomes 'active' and 'fires' an electrochemical potential thus transmitting a signal to subsequent nodes. If the neuron is not 'active', it does not 'fire' and no signal is transmitted to subsequently connected neurons. The strength of the signal transmitted to the next node is mediated by the weight on the link, in an analogous way to the way certain neurochemicals, such as dopamine and serotonin, inhibit or excite synaptic connections.

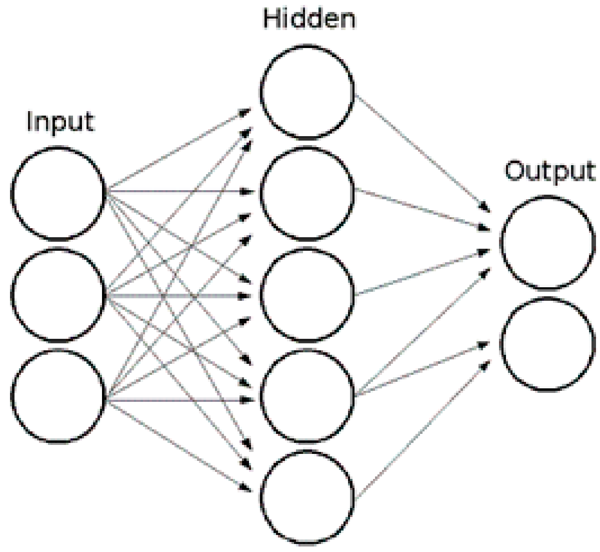


Figure 7.4. Standard hidden layer neural network structure (OpenCV API Reference, 2014).

In most neural networks, only the input and output nodes have specific interpretation. The rest of the nodes – often called hidden layers – have no specific interpretation as concepts; they simply act as part of a distributed processor, whereas, in FCMs, all the nodes have a meaningful interpretation.

ANNs are numerically 'trained' for specific problem contexts. An unsupervised learning algorithm, such as the back propagation algorithm, is used to adjust the weights on the links in the ANN and the parameters of the threshold functions on each node so that historical input data matches historical output data. The issue of when to stop training ANNs has received considerable attention in literature and practice. The ANN can then be used to predict the outputs of potential future input sets. ANNs represent a data-driven way of modelling real-world situations in cases where it is not feasible to use mathematical equations describing the system to construct and solve.

In many social and environmental decision making processes, FCMs developed by stakeholders, while used to calculate the causal flows resulting from different inputs, themselves remain static in terms of elements, links and weights. Without data- driven unsupervised training, the analogy between FCMs and ANNs ends at structural resemblance, as unsupervised learning is an important feature of ANNs.

A number of data-driven techniques for unsupervised learning of FCMs have been developed, such as the Hebbian Learning Algorithm (Kosko, 1988), Active Hebbian Learning Algorithm (Papageorgiou et al., 2004) and Song et al.'s fuzzy neural network method (Song et al., 2010). In this case, FCMs resemble neural networks more closely. Some authors see data-driven training algorithms for developing the link values in an FCM as a method for overcoming the 'subjectivity of stakeholder generated maps'. For other authors, capturing different world views and their implications may be the very point of using FCMs; and therefore data-driven training, which overrides the knowledge about world view contained in the FCMs of various groups, would not be desirable. Modellers responsible for large global climate, economic and environmental models can simply draw the FCM representing the elements and connections assumed in their model to make their modelling assumptions transparent to stakeholders and comparable to their own FCMs.

These data-driven FCM training techniques have rarely been applied in stakeholder driven social-environmental decision processes, though this is certainly possible and potentially a way of incorporating long-term ecological research data sets into the analysis, together with stakeholder knowledge (Wildenberg et al., 2014). Thus, most of the time, the FCMs used are static rather than dynamic. These FCMs are only structurally analogous to neural networks and do not undergo learning.

Reference to the 'dynamics of the FCM' refers to the dynamics of the links and weights during a training process rather than the dynamics of the underlying system (Kosko, 1988). This is different to systems dynamics models which model stocks and flows – FCMs do not model stocks and flows, they do not tell us the values of the variables themselves, or how much they are changing (effect); they do tell us about what is caused or not in certain conditions (cause). Interpreting the state of the node as the value of the concept itself leads to the development of system dynamics models, which are not the same as fuzzy cognitive maps, not necessarily even fuzzy, and do not have the same relationship with neural networks. Nevertheless, in some circumstances, it is desirable to develop simple systems dynamics models and it is important to clarify their relationship with FCMs, and how they are effectively operationalized in participatory social and environmental decision-making processes. This is described in Section 5.

7.5. Fuzzy Cognitive Maps and System Dynamics

An alternative interpretation of a weighted graph, such as the one in Figure 7.3, is as a system dynamics model, tracking stocks and flows, changes in the real values of variables as a result in changes in the values of other variables (Kok, 2009, Knight et al., 2014, van Vliet et al., 2010, Stylios and Groumpos, 2004). This gives a different physical meaning to the weights on the links and the values of the nodes. Most it changes the mathematical method for calculating model outputs and physical interpretation of results from that in CM and FCM. In this interpretation, the weight on the link is interpreted as a measure of how much effect one concept has on another rather than how certain participants are that one concept will cause another (Carvalho and Tome, 2001). That is a_{ij} represents the magnitude of the effect that a change in the real value of concept C_i has on the real value of concept C_j. In this interpretation, stakeholders are asked, for example, if C_i has a low, medium or high impact on C_j, rather than how certain they are that there is a positive or negative causal relationship between C_i and C_j, (Kok, 2009, Wildenberg et al., 2014, Vaidianu et al., 2014, Gray et al., 2013); that is, a_{ij} is a measure of 'how much effect' rather than 'how much uncertainty' about cause.

The state of the system is interpreted as the real values of the variables themselves rather than the activation level. These real values could be normalized between 0 and 1 or -1 and 1 (assuming a finite range of the variables). However, the reasons for doing so are different from those in FCMs, where the reason for the transform is because of the interpretation of state as on/off, activated/not activated, or something in between.

The initial state in this case is thus a quantification of the initial values of the variables in real terms rather than an estimate of how certain we are whether they are 'happening or not' in the first place. This potentially makes implementing this approach harder in the case where values of variable are harder to estimate, though, as will be seen, an estimate of initial value is not always needed if what is wanted is just to explore the change produced by certain policies or programmatic interventions. Again there is nothing fuzzy about the interpretation of state in this case; it is simply a single real value of the variables, perhaps normalized in some way.

To understand how this system-dynamics interpretation of the graph works and relates to FCMs and their associated calculations, consider the graph fragment shown in Figure 7.4. This fragment can be read as a change in the value of C_1 of magnitude ΔC_1 causes a change in the value C_2 of magnitude $\Delta C_2 = \Delta C_1.a_{12}$. This is summarized in Equation 9 with index j to denote the sequential nature of each change, i.e. first the change in C_1 occurs, then this causes a change in C_2. Sequence versus time in this interpretation of the graph will be discussed shortly.

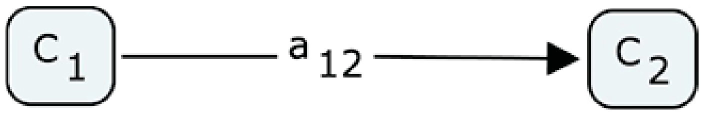


Figure 7.5. Example Graph Fragment.

$\Delta C_2 (j+1)= \Delta C_1 (j)\ a_{12}$ (9)

The total change in C_2 will be the sum of all of the change inputs to C_2 from connections with other variable concepts $C_1 \dots C_N$, where N is the total number of concepts, as shown in Figure 7.5 and Equation 10.

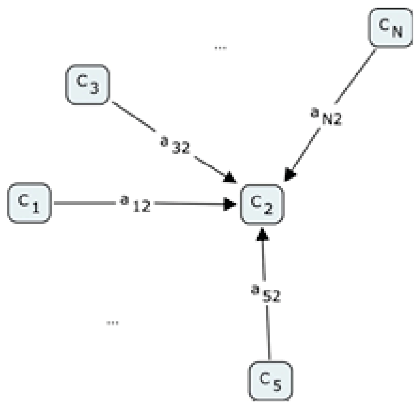


Figure 7.6. Example Graph Fragment Illustrating Inbound Connections to Node 2.

$\Delta C_2\ (j+1) = \sum_{i=1}^{N} \Delta C_i\ (j).a_{i2}$ (10)

Similarly, we can generate a set of equations for the change in value of each of the variable concepts:

$$\Delta C_1\ (j+1) = \sum_{i=1}^{N} \Delta C_i\ (j) a_{i1}$$

$$\vdots \quad = \quad \vdots$$

$$\Delta C_N\ (j+1) = \sum_{i=1}^{N} \Delta C_i\ (j) a_{iN}$$

This is equivalent to the matrix multiplication given in Equation 11.

$\mathbf{\Delta C}(j+1) = \mathbf{\Delta C}(j) \cdot \mathbf{A} = \mathbf{\Delta C}(0) \cdot \mathbf{A}^{(j+1)}$ (11)

Thus, $\mathbf{\Delta C}(0)$ is the initial perturbation applied to the system. Under the systems dynamics interpretation of the weighted directed graph generated by stakeholders, we simply have a static map of how things are connected; the system is not changing unless it is pushed. This is why, if $\mathbf{\Delta C}(0) = \mathbf{0}$, all subsequent iterations of $\mathbf{\Delta C.A}$ are also $\mathbf{0}$.

The first time the matrix $\mathbf{\Delta C}(0)$ is multiplied by $\mathbf{A}$, we obtain the direct impacts of the change $\mathbf{\Delta C}(0)$ on each of the variables: $\mathbf{\Delta C}(1) = \mathbf{\Delta C}(0) \cdot \mathbf{A}$, these changes themselves subsequently cause other changes in each of the variables: $\mathbf{\Delta C}(2) = \mathbf{\Delta C}(1) \cdot \mathbf{A} = \mathbf{\Delta C}(0) \cdot \mathbf{A}^2$; and so forth, such that the j^{th} order effect is given by $\mathbf{\Delta C}(j) = \mathbf{\Delta C}(j-1) \cdot \mathbf{A} = \mathbf{\Delta C}(0) \cdot \mathbf{A}^j$. Using Equation 11, it is possible to calculate and plot the successive order effects $\mathbf{\Delta C}(j)$ for $j = 1,\ldots,\infty$ which result from an initial perturbation $\mathbf{\Delta C}(0)$ without knowing the initial state of the system C(0) (values of the variables themselves in this case). The cumulative change which has occurred by iteration j is obtained by summing each successive order effects, including the initial perturbation itself, which itself represents a change in the initial values of the variables. This can be calculated without knowing the initial state of the system $\mathbf{C}$, and is given in Equation 12.

$\mathbf{\Delta C}_{cum}\ (j) = \mathbf{\Delta C}_{cum}\ (j-1) + \mathbf{\Delta C}(j) = \sum_{i=0}^{j} \mathbf{\Delta C}(i) = \sum_{i=0}^{j} \mathbf{\Delta C}(0) \cdot \mathbf{A}^i$ (12)

The total cumulative change that occurs as a result of an initial perturbation is calculated by summing together all successive order effects including the initial change itself, as given in Equation 13. Again, knowing the total change that results from an initial perturbation depends only on knowing the perturbation, not on knowing the initial state, or any subsequent states.

$\mathbf{\Delta C}_{TOTAL} = \sum_{i=0}^{\infty} \mathbf{\Delta C}(i) = \sum_{i=0}^{\infty} \mathbf{\Delta C}(0) \cdot \mathbf{A}^i$ (13)

If the initial state vector $\mathbf{C}(0)$ is known as well as the initial change vector then the values of state can be calculated according to Equation 14. If the initial state vector $\mathbf{C}(0)$ is not known, it is still possible to calculate the change $\mathbf{\Delta C}_{TOTAL}$ caused by any disturbance applied as an initial change vector $\mathbf{\Delta C}(0)$ as shown in Equation 13.

$\mathbf{C}(j+1) = \mathbf{C}(j) + \Delta\mathbf{C}(j)$ (14)

Since $\Delta\mathbf{C}$ is a row vector and $\mathbf{A}$ is the adjacency matrix of the graph, the similarity between Equation 11 and Equation 6 for the propagation of activation through an FCM can easily lead to the two equations being mistaken for each other, especially if the above interpretation (un-fuzzy systems dynamics) is being thought of as an FCM, though the two graphs and equations have very different meanings.

Various participatory social and environmental decision-aiding processes conducted as FCM exercises have used the systems dynamics interpretation described here, and accordingly asked participants to estimate the strength of effect rather than the degree of uncertainty of each link (Kok, 2009, van Vliet et al., 2010, Vaidianu et al., 2014, Wildenberg et al., 2014, Stylios and Groumpos, 2004) Some authors are vague, mentioning 'strength of relationship' which could be interpreted either way by participants, so we cannot be sure (Kontogianni et al., 2012, Ozesmi and Ozesmi, 2004, Gray et al., 2013). Some authors then continue to use the mathematical formulation of FCMs interpreting the row vector multiplying the adjacency matrix as some form of state, either activation level (Ozesmi and Ozesmi, 2004, Kontogianni et al., 2012), or the values of the variables themselves (Kok, 2009, van Vliet et al., 2010), and some continue to apply the squeezing function to the inputs to each node (Wildenberg et al., 2014, Vaidianu et al., 2014).

In the systems dynamics interpretation, we are dealing with magnitudes of change that result from a perturbation; it is important to know if this produces unstable effects. Runaway change would be something we would be concerned about and, therefore, reducing and bounding the change possible at each node is not desirable. For example, if increasing fertilizer subsidies would produce runaway deforestation, it is important to know this rather than have the change bounded by a squeezing function. One type of bounding of change that does make sense, for variables of finite range, is that the variable value cannot change to less than its minimum value or higher than its maximum value and this places some limitation on the total amount of change possible – once the forest is completely gone, the decrease in forest must drop to zero. This is most accurately captured by using functions with bounded support. Note that for any variables without clear bounds on their values, such as the average temperature of a planet, there is no reason the value of the variable must stay between 0 and 1 or -1 and 1 or that the total change in their value at any iteration must be between -1 and 1.

Introducing the squeezing function does introduce non-linearity into the system, but not in a practically meaningful way. When it is desirable to include non-linear relationships between variables in a system dynamics model, it makes sense for the non-linearity to be representative of the real system being modelled. A simple way to do this would be to ask participants to draw the shape of the relationship between any two variables on each link. In some cases the shape may be sigmoidal, in others exponential, power law, linear and so forth. An image of this is shown in Figure 7.7. This is actually an important step in developing better systems dynamics models, since the assumption of linear relationships between the variables is not plausible to most participants.

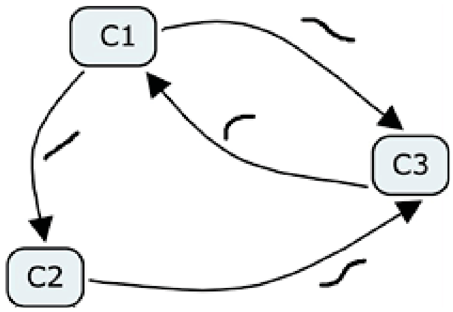


Figure 7.7. . Example graph with non-linear relationships between variables.

The system dynamics interpretation of the graph described in this section is not a dynamic model in terms of time; it represents inter-variable dynamics rather than time dynamics. The graph represents how changes in certain variables produce changes in others but, without further information, the time frame these changes take place in is not directly represented. Although time is not explicitly part of this formulation, sequences of events are. When a perturbation $\mathbf{\Delta C}(0)$ is applied to the system, the first order effects are those changes in variable values which occur as a direct result of the initial perturbation, given by $\mathbf{\Delta C}(1) = \mathbf{\Delta C}(0) \cdot A$. These first order changes then represent a perturbation which itself has effects; those effects are the second order effects of the initial perturbation $\mathbf{\Delta C}(2) = \mathbf{\Delta C}(1) \cdot A = \mathbf{\Delta C}(0) \cdot A^2$. The third order changes are those that occur as a result of the second order effects, which are given by $\mathbf{\Delta C}(3) = \mathbf{\Delta C}(2) \cdot A = \mathbf{\Delta C}(1) \cdot A^2 = \mathbf{\Delta C}(0) \cdot A^3$ and so on. We have no concept of the time frame that these sequential changes take place in – seconds or millennia. However, the concept of sequence is still relevant even without time. We are examining sequences of effects of variables on each other within a system.

Although time is not explicit, it plays an important role in the estimation of the strengths of relationships between elements. Notice that the strength we would assign to the impact of climate change on crop yield is less than fertilizer availability in the short term but higher in the longer term, since evidence shows that continuously increasing fertilizer application does not result in continuously increasing yields. People necessarily have an implicit time frame in mind when assigning relative values to the links on the map. Unless the time frame for comparison of effects is specified in the participatory process, participants may disagree simply because they are imagining relative effects over different time frames. Ultimately, each iteration of matrix multiplication represents some 'time unit'; it would be helpful if this were specified in the participatory process.

Potentially, due to the comparison with FCM equations, many authors refer to the row vector $\mathbf{\Delta C}$ in Equation 11 as the state vector $\mathbf{C}$ (Kok, 2009). This leads to post multiplying the initial state of the system $\mathbf{C}$ by the adjacency matrix, which is equivalent to subjecting the system to a disturbance the magnitude of which is equal to the state of the system itself! This also leads to the successive changes in Equation 11 being interpreted as successive states of the system, which is not mathematically correct in the system dynamics interpretation of the graph. Accordingly, various authors have calculated and plotted successive change vectors $\mathbf{\Delta C}(j)$ for $j = 0,1,2,\ldots$ and interpreted this plot as a plot of the state of the system, that is the values of the variables $\mathbf{C}$ at each successive iteration

(Kok, 2009, van Vliet et al., 2010, Knight et al., 2014). Thus, if the perturbation eventually dies out, this causes anxiety since researchers and participants alike know that the value of all state variables themselves cannot all drop to 0! However, this is not the case as this graph does not represent successive values of the variables themselves but successive changes in the values of the variables.

This has further led to some researchers calibrating the values of the adjacency matrix to produce constant non-zero values for **ΔC**, which is being interpreted as **C**. This is the same as producing ongoing displacement, that is, an unstable system. This is often done by placing 1's along the diagonal of the adjacency matrix, in positions corresponding to variables that are thought of as 'drivers', in order to produce an ongoing displacement (Kok, 2009, van Vliet et al., 2010, Knight et al., 2014). Note that, in this system dynamics formulation, a_{ii} is the magnitude of the effect that a change in C_i has on itself. Setting $a_{ii} = 1$ is equivalent to saying concept C_i has a 100% positive forcing effect on itself. In practice, a change in the value of the variable could cause a further change in the value of the variable, but there is no reason it should always be positive and always be 100%. Using separate terms for state vector and change vector could avoid these potential issues.

More generally, since we are dealing with magnitude of effect in this interpretation, there is, in fact, no reason the number on the link should be limited within [-1,1]. In FCMs, the reason the weights are within [-1,1] is because +/-1 implies certainty that the causal relationship exists, 0 implies certainty that a causal relationship does not exist, and anything in between represents a degree of uncertainty about causality. In a system dynamics model, a small change in one variable could potentially produce a much larger change in another variable, leading to weights potentially anywhere in [-∞, ∞].

Whether or not the successively higher order effects of the initial perturbation die out (that is, go to zero), stabilize at finite values, or tend to infinity depends on the behaviour of A^n as n tends to ∞. This depends on the spectral radius of the adjacency matrix (that is, the eigenvalue of maximum modulus, and we note that this eigenvalue need not necessarily be unique). There are three cases, according to whether the spectral radius is less than 1, greater than 1, or exactly 1:

- Case 1: Spectral radius < 1. A^n tends to zero as n tends to ∞; thus the ripples of the initial perturbation will eventually die out, leaving a stable non-zero total displacement.
- Case 2: Spectral radius > 1. The norm of A^n tends to ∞ as n tends to ∞, and so at least one element of A^n tends to ∞. Thus the initial perturbation has the potential to produce unstable ripples, also leaving an infinite total displacement (see discussion below).
- Case 3: Spectral radius = 1. The norm of A^n either tends to some constant value as n tends to ∞, or grows more slowly than geometrically (Gelfand's formula). Thus the effects may eventually stabilise to a constant value or may continue to grow slowly. In either case, the total displacement will not have a finite value. Note that, even in the case where a constant perturbation exists, the total displacement cannot have a finite value, as the perturbation never stops, and so the total displacement must grow without bound.

Though a spectral radius < 1 guarantees a finite total displacement, this does not rid us of the need to conduct the matrix multiplication described in the previous sections in those cases where the dominant eigenvalue is ≥ 1. The reason for this is that, depending on the nature of feedback cycles within the system and the precise nature of the perturbation, unstable behaviour may or may not permeate the system. This means that it is possible for some perturbations to produce stable consequences and others to produce unstable consequences in systems where the entire adjacency matrix has spectral radius ≥ 1. In all cases, the matrix multiplication with the initial perturbation is necessary to determine the total change.

In this type of model, combining graphs generated by different stakeholders is more complicated than in FCMs, where degrees of certainty about causality can be improved by incorporating the knowledge of more experts and stakeholders additively (Kosko, 1988). In the system dynamics interpretation, there is debate about whether the weights should be averaged or some other method used to obtain a composite graph (Ozesmi and Ozesmi, 2004).

In summary, this interpretation of the graph is essentially a linear system dynamics model. It is not fuzzy since there is no uncertainty included in the model – just magnitude of effect. This interpretation completely changes the nature and implementation of the participatory process: where one explores uncertain knowledge asking participants 'How certain are you that A causes B' and the other explores perceived relative magnitude of effect asking 'What is the magnitude of the effect A has on B, how strong is the effect compared to other weights you have assigned?"

While it is not fuzzy, building a simple systems dynamics model is very useful thing to do with participants in many cases, particularly when it is desirable to quantify the effect of different interventions on different variables. System dynamics models permit estimates, such as 'increasing fertilizer subsidies by 20% decreases deforestation by 5%', according to the world view represented in the model. The process of building the system dynamics model allows for an exploration of different stakeholders' system boundary judgements and perceptions of the relationships elements of the system of interest, just as in the case of FCMs.

Note aggregating graphs generated by different stakeholders is much more complicated in the case of system dynamics models, as we are not simply becoming more certain, because more people say a particular link exists. Not surprisingly, studies using the system dynamics interpretation have shown that aggregating maps from different stakeholder groups can have very different outcomes about the perceived impacts under the same scenario, given variation in knowledge structuring across groups, and the aggregation technique itself has a significant impact on outcomes (Gray et al., 2012).

7.6. What is the Difference?

This section uses a single weighted directed graph to illustrate that there are significant consequences for decision-making if the same graph is interpreted as an FCM (Kosko, 1986) or, as it has recently been appropriated in environmental decision-making, as a system dynamics model (Kok, 2009). The weighted graph in Figure 7.3 was chosen, as it is deliberately simple and abstract. Recall the adjacency matrix A, as given in Equation 2.

Interpretation of graphs is not arbitrary; each interpretation of the weights on links and the state of the concepts corresponds to a specific mathematical formulation, which determines the meaning of the results in that context. While we can choose how to interpret the state of the concepts and the meaning of the weights on the links in formulating the graph, this choice specifies the mathematics and its meaning; we cannot choose to apply arbitrary mathematics to arbitrary interpretation and the results are not then 'up for re-interpretation'.

Within each interpretation, there is a mathematically correct way to go about calculations. Various published FCMs in the environmental literature use equations that are inconsistent with the interpretation of the graph, or are simply internally mathematically incorrect, as discussed above. The following subsections apply mathematically correct calculations, consistent with each interpretation.

7.6.1. Interpretation as an FCM

Interpreting the graph in Figure 7.3 as an FCM, the weights are interpreted as a measure of how certain we are that one concept causes another to happen, or not to happen. The states are interpreted as a measure of how confident we are that a certain concept is activated (happening) or not.

It is possible to calculate what is 'caused' given any initial conditions using Equation 6 for memory less FCM or Equation 8 for one-state memory. For the sake of this illustration, we set the initial conditions as [1, 0, 0.5], and use the same vector in the system dynamics interpretation for comparison. We use the unipolar sigmoidal function given in Equation 4 as the squeezing function for the FCM with the parameter $\lambda = 0.5$.

The successive state activations calculated using Equation 6 for a memory less FCM are shown in Figure 7.8. Quite quickly, C1 settles at 0.54, C2 at 0.53 and C3 at 0.47. As all of these numbers are very close to 0.5 (perfect uncertainty about whether something is happening or not), we are very uncertain about the condition of C1, C2 and C3 given the initial conditions. What this means is that, starting from certainty that C1 is happening, C2 is not happening and complete uncertainty about what C3 is doing, we can't really tell what will happen with the knowledge we have, though we lean towards C1 and C2 happening and C3 not happening, but not with much confidence. In fact, the fixed point (0.54,0.53,0.47) is reached from all starting conditions.

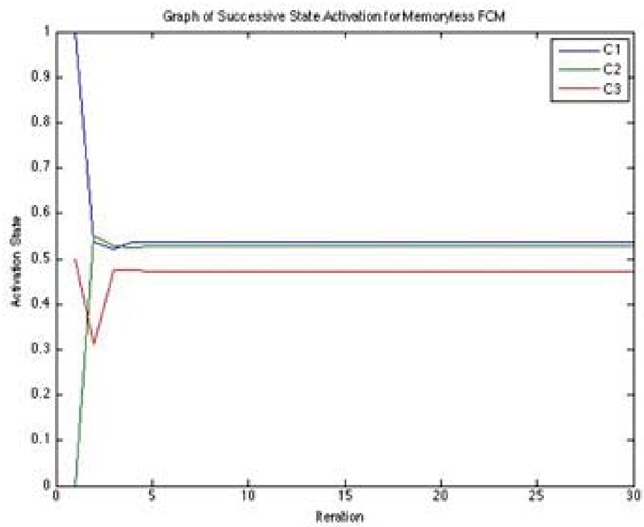


Figure 7.8. Graph of Successive State Activation calculated using Equation 6.

The successive state activations calculated using Equation 8 for one-state memory FCM are shown in Figure 7.9. Quite quickly, C1 settles at 0.59, C2 at 0.59 and C3 at 0.55. As all of these numbers are very close to 0.5 (perfect uncertainty about whether something is happening or not), we are uncertain about the condition of C1, C2 and C3 given the initial conditions, although slightly less uncertain than in the memory less case. As in the previous case, we can't really tell what will happen with the knowledge we have. We lean towards concluding that all concepts are happening but not with much confidence. In fact, the fixed point (0.59,0.59,0.55) is reached from all starting conditions for this FCM.

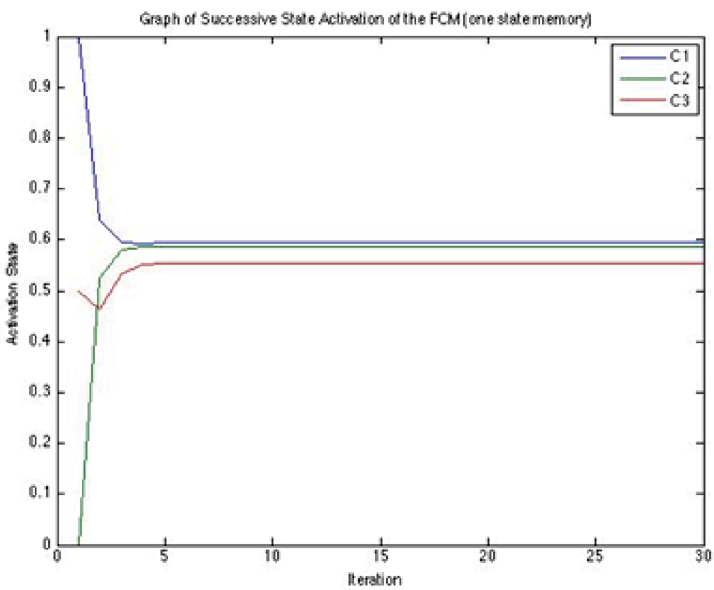


Figure 7.9. Graph of successive state activation calculated using Equation 8

What both of these FCM calculations have told us is how certain we are that certain things are happening or not happening, based on a set of initial conditions. In this case, we are quite uncertain about everything. Accordingly, this example also illustrates that, in some cases, the FCM serves to highlight how uncertain the inferences we make based on our knowledge systems are. Potentially, this could be helpful in decision-aiding and open up space for entertaining alternative world views, more information, and humble and adaptive decision-making.

7.6.2. Interpretation as a System Dynamics Model

Interpreting the graph in Figure7.3 as a system dynamics model, the weights are interpreted as measuring how a change in the value of one variable is transmitted to a change in the value of the connecting variable. In the simplest case of a linear system dynamics model, the weight is the slope of the straight line describing the relationship between the two concepts. This line could have any slope $\in [-\infty,\infty]$. There is no reason the weights on the links need to be $\in [-1,1]$, since a small change in one variable could produce a larger change in another variable. More general system dynamics models may include non-linear functions to describe the relationships between variables.

The state of each concept is its magnitude in real terms; it could be normalized to be $\in [0,1]$ or [-1,1] or not. Functions with bounded support may be used to calculate the state values in cases where variables have finite range. However, pushing the sum of inputs through a squeezing function does not make sense in this interpretation. No squeezing function has been used here for mathematical correctness. The vector that multiplies the adjacency matrix, **A** is the perturbation, or change, applied to the system. Note that, in this type of system dynamics model, nothing is changing unless an external push is applied.

Interpreting the graph in Figure 7.3 as a system dynamics model, it is possible to calculate the effect of an initial perturbation using Equation 11. For consistency, the initial perturbation is set to [1, 0, 0.5]. In this model, the initial perturbation eventually dies out so that, as shown in Figure 7.10, the successive changes become 0.

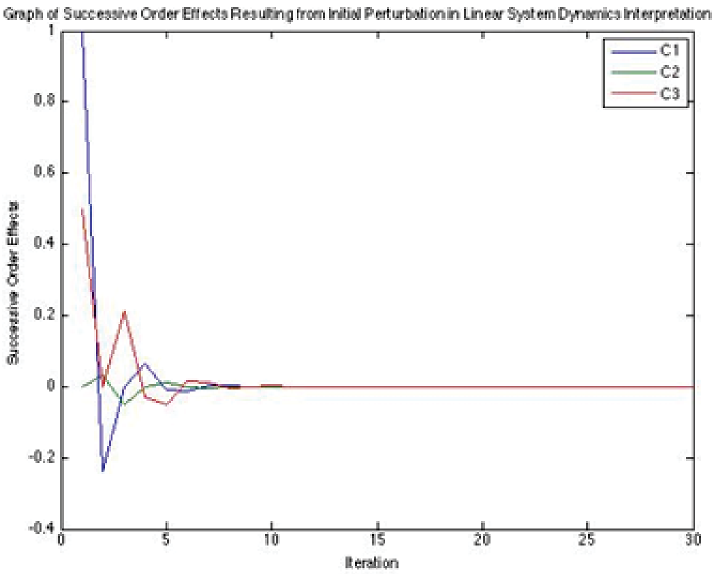


Figure 7.10. Graph of successive order effects resulting from initial perturbation in a system dynamics interpretation of the graph in Figure 7.3

The cumulative change, calculated using Equation 13, resulting from the initial perturbation at each iteration, is illustrated in Figure 7.11. The final change that resulted from the initial perturbation is C1 increased by 0.81, C2 decreased by 0.01 and C3 increased by 0.65.

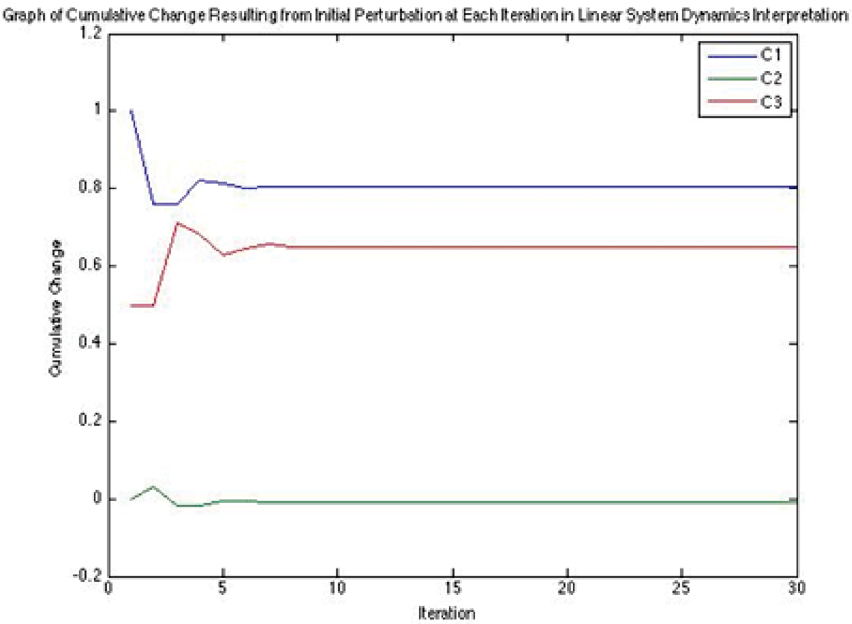


Figure 7.11. Cumulative change at each iteration, resulting from the initial perturbation in a system dynamics interpretation of the graph in Figure 7.3.

In this example, the initial state of the system was not originally given. Say it is [0,1,0], then the final state of the system as a result of the perturbation would be [0.81, 0.99, 0.65]. The model does not explicitly tell us how long these changes take to occur. However, the estimation of relative weights does rely on a notion of a time unit, and thus each iteration could be thought of as one time unit.

There are situations where using a system dynamics model might be desirable, as well as or instead of an FCM, and a linear first approximation could be a good start and provide some insights before introducing more complexity and nonlinearity. In cases where linearity is obviously not a reasonable assumption, nonlinear system dynamics models can be built, the downside being that more expertise is often required for computation in this case.

7.6.3. Discussion

Taking exactly the same graph, one can obtain entirely different inferences for decision-making, depending on how the graph is interpreted and calculations carried out. Accordingly, it is important that there is consistency in the interpretation that is used to generate the graph, to undertake calculations and to interpret the results.

The option to mix and match equations with interpretations according to fancy does not exist without producing mathematical gibberish. Equations are equivalent to sentences, describing the relationships between the components of the system and how they change relative to each other, and, as such, they have physical interpretations. The physical interpretation that gives rise to the equations, used consistently throughout calculation and interpretation of results, produces meaningful understanding.

FCM models can tell us what our knowledge system indicates will be caused from a particular intervention or any given set of initial conditions, together with the uncertainty associated with this inference. The system dynamics version can tell us the magnitude and direction of change of the values of the variables in the model, for a given initial perturbation. This form of the model does not include time; it only models how the variables change with respect to each other, not time. Accordingly, it does not tell us the time frame these changes take place in, and is not changing unless an external change is applied to one of the variables since $0 \cdot A = 0$.

The system dynamics interpretation of the weighted directed graph developed in participatory processes are not fuzzy at all; there is no uncertainty in the model [1]. The links that are there exist with complete certainty, the strength of the relationship between variables is also a fixed number, and keeping it between 0 and 1 does nothing save limit the slope of the line between two variables and eliminate the possibility that a small change in one variable might produce a larger change in another.

For FCM, the results are sensitive to choice and parameterization of squeezing function and to the amount of memory included. For system dynamics, there is no reason to limit the

[1] Fuzziness could potentially be added by asking people for a range of values for the weight on the link and how certain they feel about this estimate.

weights or the state values to an absolute value between 0 and 1, and pushing the sum of the inputs to a concept node through a squeezing function is mathematically nonsensical.

'FCMs' are being used extensively to aid social and environmental decision-making processes, to capture different worldviews and explore the causes and effects of different variables. In the practice of social-environmental decision-aiding, it turns out that many FCMs are not fuzzy, and are, in fact, system dynamics models with some inherited mathematical features from the original formulation of FCMs [2] consistent with that interpretation physically and mathematically. This may be because, in many cases, system dynamics models supply the information stakeholders and researchers are interested in: the magnitude and direction of change in the values of variables, which result from particular disturbances or interventions.

FCMs, neural networks and system dynamics models can all be constructed through participatory processes. The process of defining the boundaries of the system of interest by deciding what factors are important to include and what can be ignored, how these factors relate to each other, which disturbances the system should be subjected to, and which interventions are possible, is hugely useful irrespective of the type of model being built or even whether a model is being built at all.

However, beyond this FCM, neural networks and system dynamics models are different models that require different data in their formulation and answer different questions. FCMs have a structural relationship with neural networks and, in the case where an unsupervised learning algorithm is applied to adjusting the weights of the FCM, the FCM is a neural network. However, there is a fundamental difference between FCMs and system dynamics models in that one models uncertain and ambiguous causes and the other models unambiguous effects. For FCMs and system dynamics models the placing of weights on the links of the graph is very different. At this stage in the process, FCM asks how certain are you that this causal link exists whereas system dynamics models ask what is the magnitude of effect of one variable on the other.

Though FCM and system dynamics models are somewhat confabulated in the social-ecological and resilience literature (Kok, 2009) it is important to differentiate between fuzzy cognitive maps and system dynamics models in this field. The choice of FCM versus system dynamics model changes:

- How the activity is framed and explained to participants in terms of what is being done, what the purpose is and what outcomes and outputs should ideally be.
- It changes what questions you should ask participants and what data to collect. For FCM links, 'How certain are you about the existence of this causal relationship?' versus, 'How much does this variable affect the other?' are very different questions, which are likely to produce different weighted graphs.

[2] For example, as limiting link weights to an absolute value less than 1, using a squashing function on the value of the state of each concept, or even putting 1's on the diagonal of so called 'drivers'. These conditions make physical and conceptual sense in the FCM formulation but not in the system dynamics model.

- It changes the type of information you can get from the model. FCM models can tell us what our knowledge system indicates will be caused from a particular intervention or any given set of initial conditions, together with the uncertainty associated with this inference. The system dynamics version can tell us the magnitude and direction of change of the values of the variables in the model, for a given initial perturbation.
- It changes the mathematical rules of the calculations that need to be applied.

All of these items have a significant impact on the decision-aiding process and on the conclusions and recommendations drawn for action. A coherent mathematical model with consistent conceptual interpretation and practical implementation is important for the quality of the results and the meaning derived from the exercise. The clearer practitioners are themselves about what is going on here, the more simply they can explain the method and the more readily they can facilitate the understanding of participants, collect meaningful representations and conduct logically rigorous and meaningful calculations providing useful results, robust conclusions and recommendations.

Some might argue that considerations relating to mathematical calculations don't matter, because the important thing is having a legitimate reason to get participants together to discuss their views and it is the discussion and the map they draw that matters. Indeed, 'the process of creating a model with stakeholders is often worthwhile in and of itself for its engagement value, and for the insights offered to the researcher' (Knight et al., 2014). However, further calculations are done, and that this is the case is often part of legitimizing the activity and drawing in the stakeholders. Also, the faith people have in a methodology that is perceived to be advanced mathematically 'might cause results to be accepted without a prudential degree of skepticism'(Kontogianni et al., 2012). Since the inferences made as a result of the activity are highly sensitive to the considerations above, it is important that those calculations are meaningfully conducted and interpreted.

The cognitive maps (elements and linkages) generated by participants are used in further analytic techniques, and, through the analysis, can crucially shape the mindsets of participants and assessment of the merit of any proposed policies and programs in the ultimate decision-making process (Ulrich, 1983). It is, therefore, equally key to ethical and effective policy and program development that the analysis with its underlying mathematics be an accurate model and a correct inference of the knowledge is elicited from participants.

FCMs continue to be used and continue to have a lot to offer; so do system dynamics models, though they serve different purposes. Work has been done to put cause and effect together. Theoretically it should be possible to ask people where they think causal links exist, how certain they are that the causal link is there, and also what the magnitude of effect is. In order to 'fuzzify' the magnitude of effect, participants could be asked for a range of values instead of just one. This is potentially easier and quicker than estimating single values, as the entire range suggested by all participants can be adopted. Work is currently being done on mathematical approaches which incorporate uncertainty in both cause and effect in such ways (Papageorgiou and Salmeron, 2013). FCMs, system dynamics and other forms of participatory modelling contain many possibilities for further research and development. Harnessing technology to involve as much of the population as possible in fun or game-like model development is another interesting topic. For now, we will seek to use a simple linear system dynamics model – the kind most frequently used under the heading of FCM in social-environmental decision-aiding literature – with correct mathematics, to illustrate how any model can be used to quantify resilience.

7.7. Application of Resilience Measures

The calculations presented thus far allow us to quantify the response of the system of interest to various disturbances over a particular time frame. However, without a measure of desirability, it is still not possible to say anything about resilience.

In order to quantify resilience, the following is needed:

- A model of the system of interest which quantifies the response of the system to disturbance or change, which itself requires:
    - Which variables to include in the model and which, out of the universe of possibilities, can be left out – this includes the resilience 'of what' question.
    - What type of change we want to model, this includes knowing what types of disturbance since the disturbances need to be capturable by the model. Thus, this includes the "to what" question.
    - Knowledge of how the elements of the system relate to each other and interact. This can be expressed in equations, which is the case for both FCM and system dynamics models. Or the relationships can be expressed in terms of rules of interaction for an agent-based simulation.
- A definition of what constitutes desirable or undesirable change.

According to the conceptual framework given in Chapter 4 and the operational framework given in Chapter 5, for a specific system (of what), and a particular disturbance of a particular magnitude (to what), the resilience of the system is the capacity of that system to respond to that disturbance without incurring any adverse consequences as judged by a particular observer (from whose perspective), over a particular time frame (over what time frame). Thus, if f is the function that defines the desirability conditions of the system, called the 'preference function', then the resilience of the system to disturbance d, over time frame Δt with respect to that preference function f is given by Equation 15,

$$\text{Resilience}_{f,d,\Delta t} = f(\Delta t) - f(0) \qquad (15)$$

This measure decouples resilience from a single basin, as discussed in Chapter 3. Desirable features do not necessarily neatly match the boundaries of a basin of attraction (there may not even be attractors depending on the model type) and also because this allows the system to adapt and benefit rather than staying only within a neighbourhood of one equilibrium.

Equation 15 was developed by Dr Steven Lord, in collaboration with the author of this thesis, to develop and test mathematical measures of resilience that correspond to the conceptual framework presented in Chapter 4. Dr Steven Lord developed an advanced and comprehensive set of mathematical measures for resilience in discrete, continuous and stochastic models (Lord, 2007a, Lord, 2007b, Lord, 2007c). The formal exposition of these mathematical measures and their associated proofs of uniqueness and existence are beyond the scope of this thesis; they are not easily accessible to resilience researchers and practitioners, whom the content of this thesis is aimed at. Considering the difficulties social and environmental decision-making practitioners have with the use of FCMs, as described above, it seems wise to avoid abstract mathematical terminology as much as possible and stick with simple illustrative examples. That is the purpose of this section. This section applies the measure described by Equation 15 to a food system model.

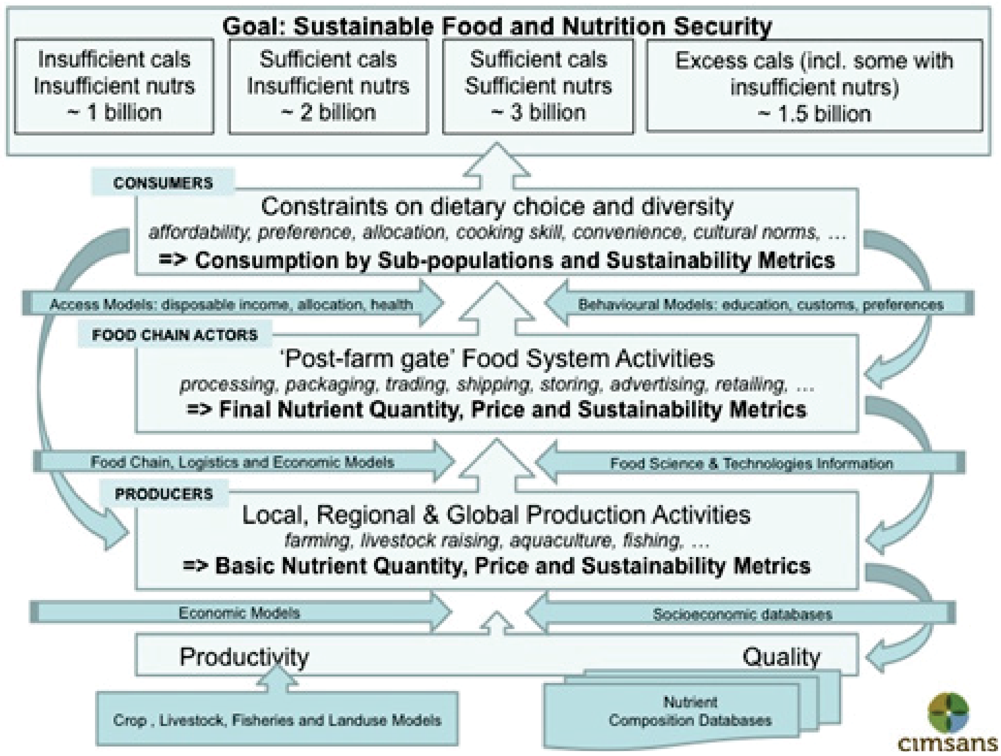


Figure 7.12. CIMSANS Food System Diagram (Ingram, 2013).

The author led an online focus group comprised of food system researchers from the University of Oxford, University of Wageningen, International Institute for Applied Systems Analysis (IIASA) and the CGIAR Climate Change Agriculture and Food Security (CCAFS) Program, during August 2014, in order to construct the food system influence diagram shown in Figure 7.13. The CIMSANS food system diagram (Ingram, 2013), shown in Figure 7.12, was used as a starting point for the development of the influence diagram. Development of the diagram was informed by knowledge of the International Food Policy Research Institute's IMPACT model and IIASA's Globiom model through Amanda Palazzo and Joost Vervoort. Development of the diagram was also informed by the results of the CCAFS Systemic Integrated Adaptation Research Program through the author and Joost Vervoort.

Figure 7.13 is meant as an illustrative example of a particular world view regarding food systems; it is by no means an objective or exhaustive model and there are other world views about food systems that would be represented by different sets of elements and different relationships. Many things have been left out; for example, the impact of culture on food preferences, many types of ecosystem services such as pollination and its impact on food production and ecosystem health, and the impact of wealth inequality on food access and affordability. Obviously there are a lot of factors that contribute to climate change other than agricultural emissions, and so on. There are many different ways to frame relevant factors, many different factors that could have been included or left out, and there are those who would disagree with the way these links have been drawn. This map was constructed to be broadly representative of a sustainable food discourse (which understands itself as different to technology-driven, production-driven or profit-driven discourses).

The desired features relevant for resilience (those features that must be preserved under change, or can 'improve' by changing in specified ways) are included in the FCM or system dynamics model so that the impact of disturbances or interventions on those features can be calculated. For example, we are interested in food security in this example, so it has been included in the model in Figure 7.13. The types of disturbance that we think affect the system (and how) are also included; for example, this model allows us to investigate the response of the system to disturbances such as different degrees of climate change, sudden fluctuations in food prices or quantities of food available. The model also allows us to explore the effect of different interventions, such as programs providing nutritional education and cooking skills, policies to reduce agricultural emissions, or an increase in fertilizer subsidies.

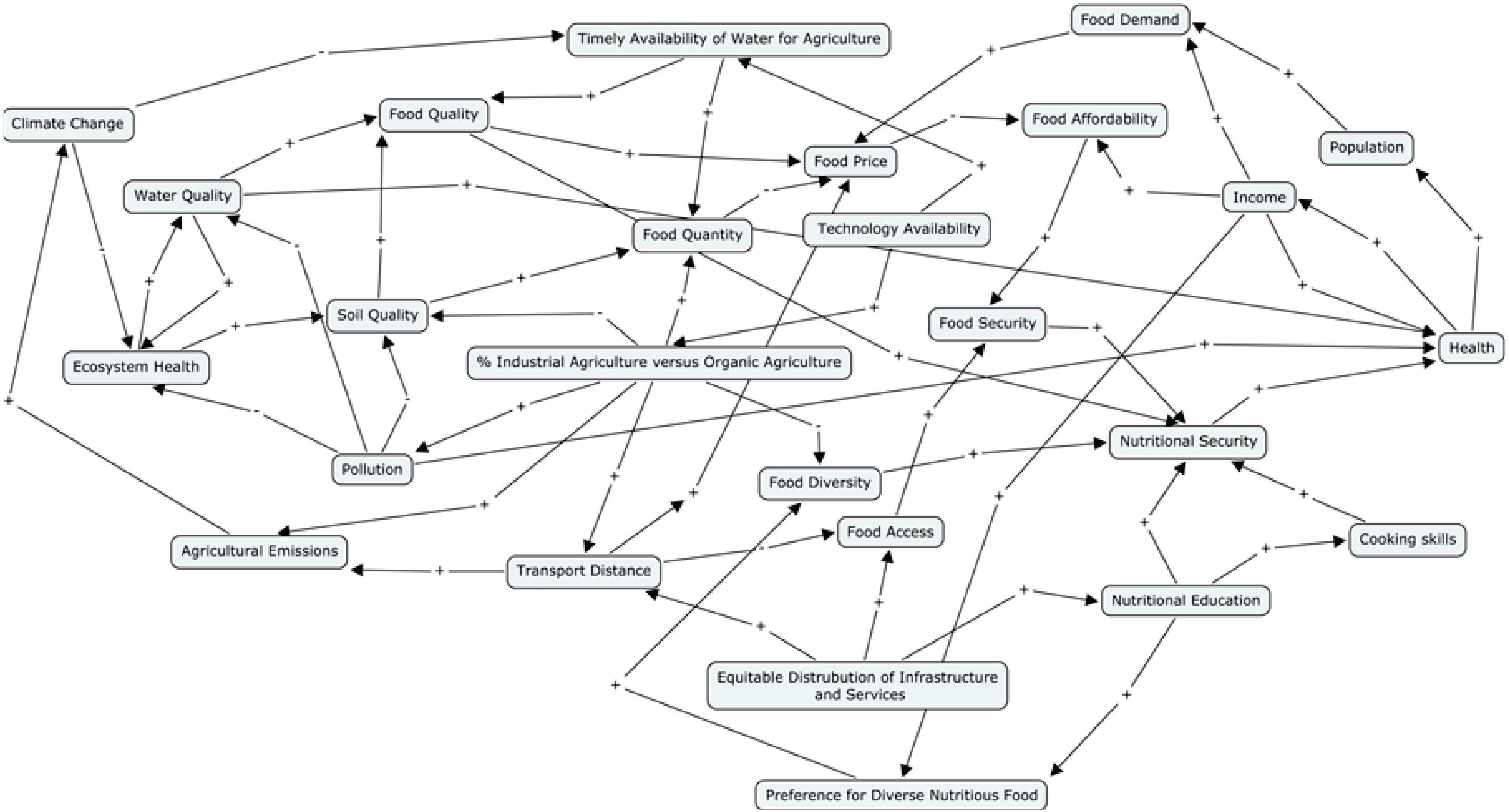


Figure 7.13. Food system influence diagram.

This influence diagram was used as the basis for the construction of both an FCM and a linear system dynamics model by asking two questions about each link in the diagram respectively: 1) How certain are you that A causes B? Does A cause B a little, sometimes, a lot, always, and so forth? 2) What is the magnitude of the effect that a change in A has on B? If A increases/decreases by ΔA, does B increase/decrease by more or less than this amount? The answers to these questions for all links were recorded in Figure 7.13. This figure demonstrates that the process of producing an FCM versus the process of producing a system dynamics model produce two entirely different sets of weights. We may think something has a very strong effect but be very uncertain about it, or think that this only happens sometimes.

The direction of causation and the direction of effect are the same, but the degree of causation (sometimes, a lot, always) and the magnitude of effect (high, medium, low) are not the same quantity. Consider the link between Climate Change and Ecosystem Health in Figure 7.14: the FCM says there is almost definitely an effect, but it doesn't say how much. The SD assumes there is an effect and that it is -0.2.

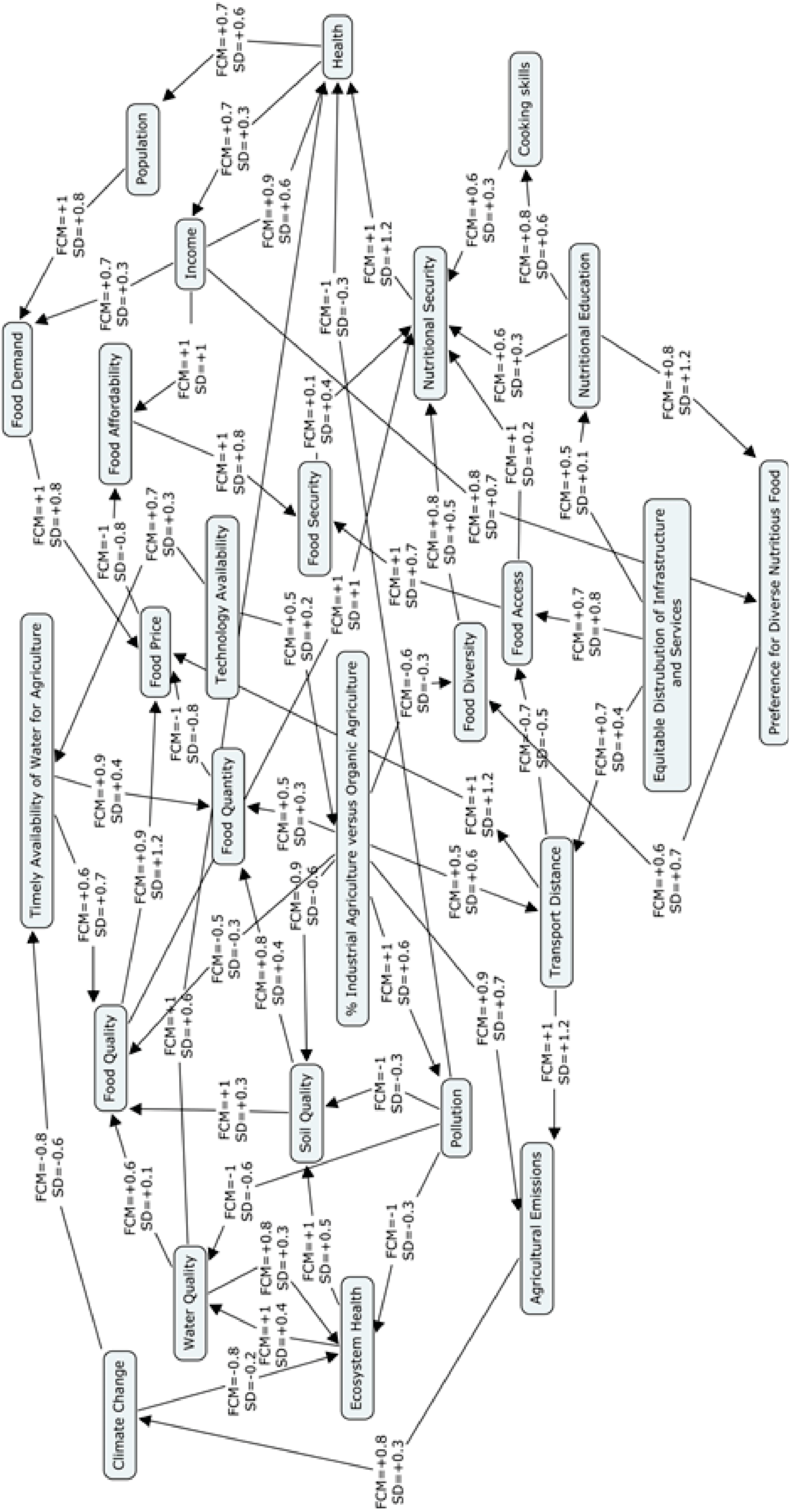


Figure 7.14. Food systems directed graph with FCM link weights and SD link weights.

Calculations indicate that the FCM converges to one single stable fixed point irrespective of starting conditions. This means the FCM can tell us what the outcome of our belief set is, and it would be interesting to compare this with the outcomes of different belief sets as represented by different FCMs. However, this FCM turns out not to be useful for exploring how different interventions or policies might affect desired features of the system, and thus is not useful for resilience. FCMs are only useful for modelling resilience where they do not converge to a global stable fixed point irrespective of initial conditions [3] .

The system dynamics model turns out to be more useful for applying the resilience measures. We will explore the resilience measures when the property of interest is food security and when it is food security and nutritional security, and therefore examine the merit of different interventions for building resilience.

A 30% increase in climate change produces the cumulative changes shown in Figure 7.15. Changes in the following variables are not caused by an increase in climate change in this model: nutritional education, cooking skills, preference for diverse foods, technology availability, the type of agriculture being practiced, agricultural emissions and pollution. All other variables decreased, with the exception of food prices, which increased. Ecosystem health, water quality, soil quality, timely availability of water resources for agriculture, food quality and quantity, population, income, affordability, food security and nutrition security, and health all decline.

How the measure of improvement or deterioration is defined will determine resilience. From the perspective of food retail profits, the increase in food price is potentially beneficial if we do not look at other variables. If we are looking at food security, or food and nutritional security, this is clearly not a beneficial change. Two preference functions are defined in order to quantitatively demonstrate how the measure of improvement critically affects the resilience of the system to various types of disturbance or change. Preference function 1 is based only on food security and increased food security is associated with increased desirability, thus

$$f(x) = x,$$

where x = food security.

Preference function 2 is based on both food security and nutritional security, in this case with equal weight:

$$f(x,y) = 0.5x + 0.5y,$$

where x = food security, and y = nutritional security.

[3] Also they are useful where policies or interventions directly affect links or weights on links rather than just the state variables. This would imply changing the map so it has not been covered in this illustrative example.

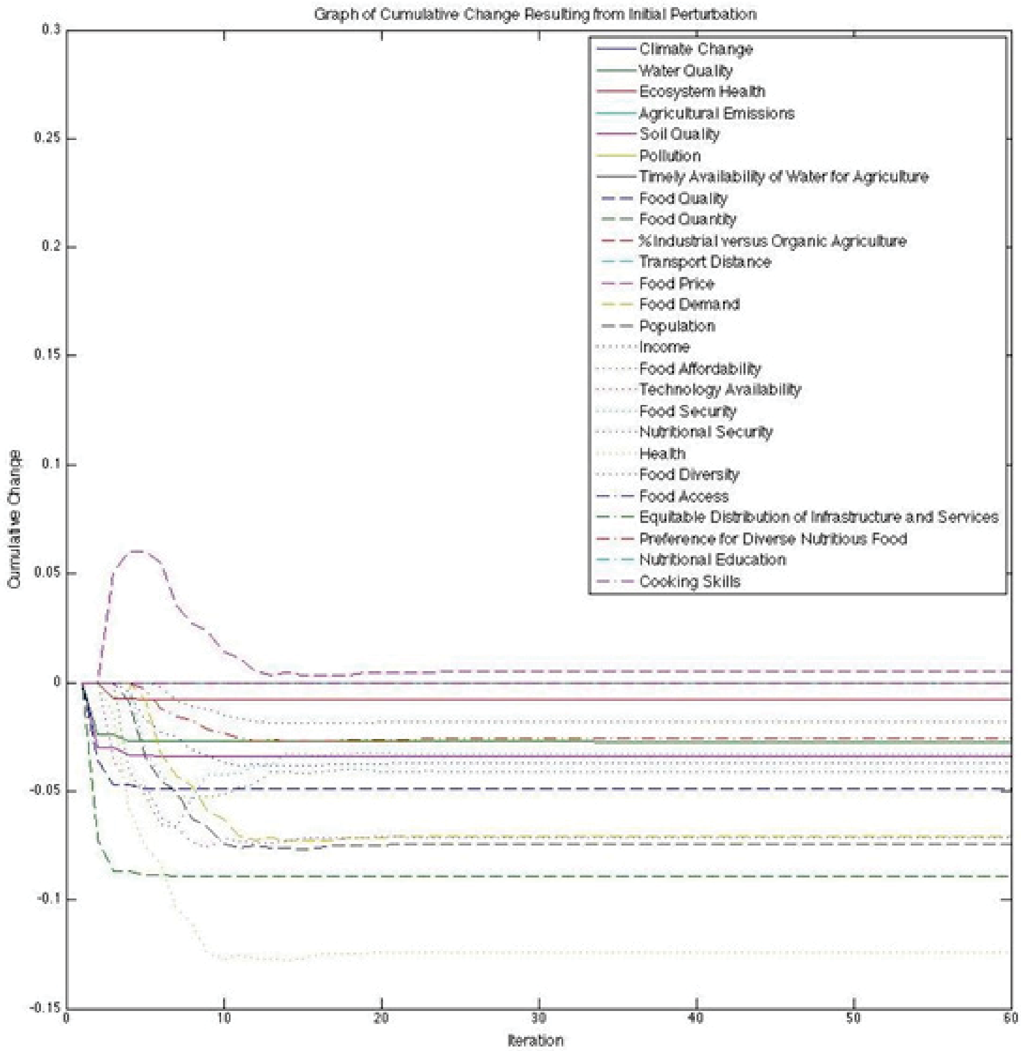


Figure 7.15. Cumulative Change Produced by 30% Change in Climate.

Using preference function 1, the resilience of the system to a 0.3 increase in climate change is -0.0329. As this number is negative, this demonstrates that the response of the system to the disturbance results in deterioration according to this preference function. Using preference function 2 the resilience of the system is (0.5*-0.0329)+ 0.5*(-0.0712) = -0.0521, which is 2% worse than if we had only considered food security.

Now let's examine the effects of different interventions to build resilience in the face of climate change, using these two preference metrics. Figure 7.16 shows the change in the system which results from a 0.3 increase in climate change together with a 0.5 decrease in industrial agriculture in favour of organic agriculture. In this model, timely availability of water for agriculture does decrease, affecting production; however, the drop in agricultural emissions due to the switch from industrial to organic agriculture also reduces the impacts of climate change eventually.

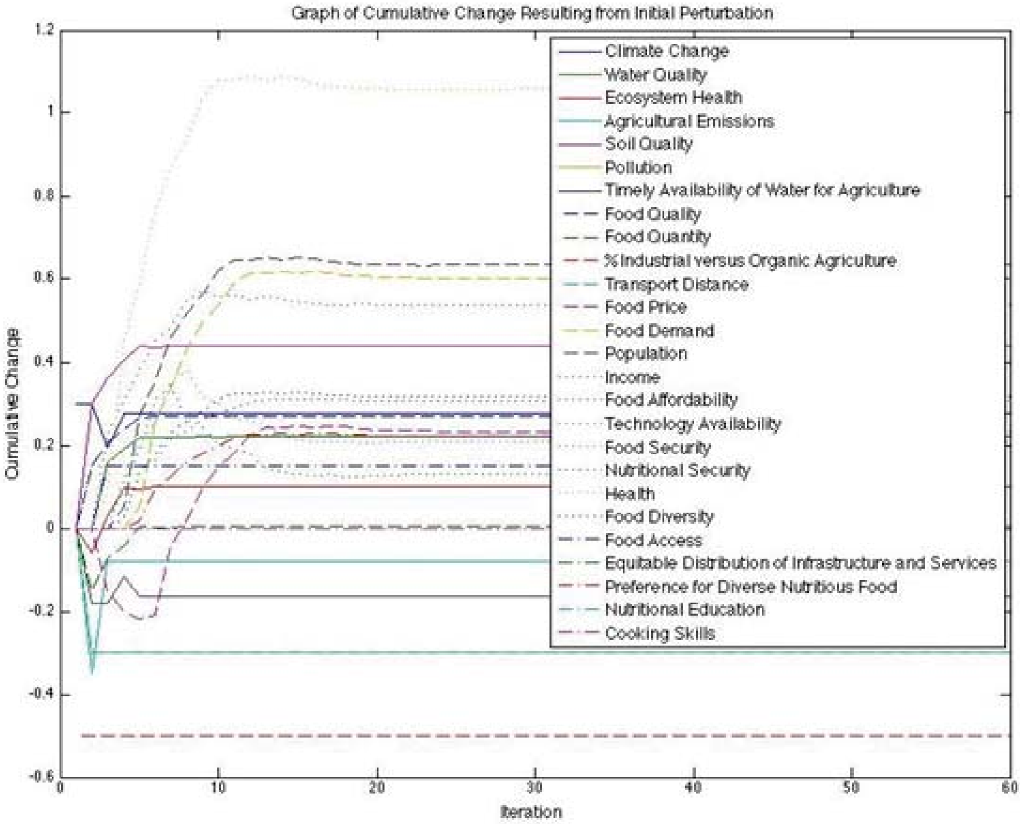


Figure 7.16. Cumulative Change From +0.3 Climate Change with 0.5 Drop in Industrial Versus Organic Agriculture.

The increases in water quality, soil quality, ecosystem health, and decreases in pollution all increase food quantity and quality, even in the face of climate change. Food price is increased by the shift to organic; however, incomes also increase due to improved health, and food availability, food affordability and food security are improved. According to preference function 1, the resilience of the system to climate change with a significant (0.5) shift towards organic agriculture is 0.2095. This is an increase in resilience of 0.2095 - (-0.0329) = 0.2424 due to the shift towards organic agriculture. According to preference function 2, the resilience of the system to climate change with a significant shift to organic agriculture is 0.5*(0.2095)+0.5*(0.5376)=0.37355. This is an increase in resilience of 0.37355 - (-0.0521) = 0.42656. The second preference function gives us almost double the increase in resilience. This is in large part because nutritional security is affected by the nutritional content of food, which according to the world view represented in this model, is higher under organic production than industrial. Note that not everyone agrees with this perception; it is the view of the participants in the focus group that generated the map.

This model would lead us to conclude that organic agriculture could do a very great deal for both food and nutritional security, which is certainly not a view shared by those in favour of large-scale industrial agriculture to feed the world (Wegner and Zwart, 2011). That is because it is representative of a particular world view and a different model might not include the same environmental feedbacks, or concerns over food quality that are played out in this model.

For example, this model explicitly includes soil and water quality, and ecosystem health and their impact on food quality and accordingly on nutritional security. It also includes the impact of farming technique on soil and water quality and thus reflects how worldviews that incorporate these relationships express the importance of sustainable, ecosystem friendly farming approaches.

Consider also another disturbance – a hike in food prices by 50%. The cumulative effect of a 0.5 food price hike are shown in Figure 7.17. The food price hike does not affect climate change, agricultural emissions, timely water availability for agriculture, pollution, ecosystem health, soil quality, water quality, food quality or quantity, mode of production or transport distance. It does, however, cause significant decreases in food demand, population, income, food diversity, food availability, food security, nutritional security and

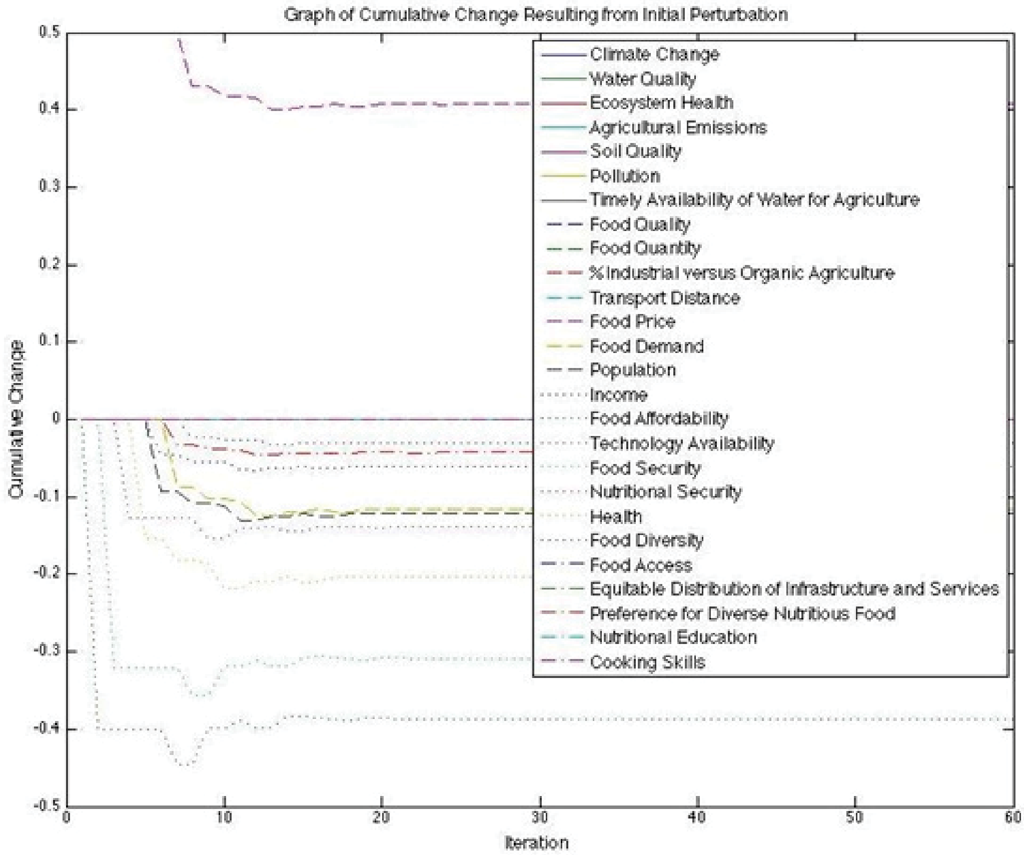


Figure 7.17. Cumulative change caused by food price hike of 0.5.

According to preference function 1, the resilience of the system to this food price hike is -0.3095 and, according to preference function 2, is 0.5*(-0.3095) + 0.5*(-0.1387) = -0.22. So, with preference function 2, the system looks more resilient to price hikes than with preference function 1.

This type of modelling also allows us to look at the effects of these disturbances and of various interventions in isolation and combined with each other. The combinations will also make a difference to the relative numerical values of resilience calculated for the same system.

Note that, since nothing is changing in the models given, unless there is an external perturbation, we can push the model and 'see where it lands'. Thus, in the considerations above, resilience is examined over the period taken until the change caused by the initial perturbation has stabilized. This is the way 'over what time frame' is specified in this investigation. Examination of any of the cumulative change graphs shows that fluctuations in the variables of interest during the initial period until the disturbance stabilizes would mean that different qualitative values of resilience would have been obtained if the calculation had been applied over a time period shorter than the time the model took to stabilize.

7.8. Conclusion

The operational framework presented in Chapter 5 applies as much to quantitative measurement of resilience as it does to any qualitative studies or any practical attempts to characterize or build resilience on-the-ground as described in Chapter 6. Quantifying resilience is not made objective through the use of rigorous mathematical modelling techniques and transparent, replicable measures. It still entirely depends on the specification of resilience 'of what, to what, from whose perspective and over what time frame', all of which are normative judgements that will be made differently by different inquirers, depending on their purpose, values, world views and so on.

This chapter has applied mathematical measures consistent with the conceptual framework presented in Chapter 4. In order to apply these measures, the operational framework presented in Chapter 5 had to be applied. In order to quantify resilience, the following is needed:

- A model of the system of interest which quantifies the response of the system to disturbance or change, which itself requires the following:
    - Which variables to include in the model and which, out of the universe of possibilities, can be left out – this includes the resilience 'of what' question.
    - What type of change we want to model; this includes knowing what types of disturbance, since the disturbances need to be capturable by the model. Thus, this includes the 'to what' question.
    - Knowledge of how the elements of the system relate to each other and interact. This can be expressed in equations, or the relationships can be expressed in terms of rules of interaction for an agent-based simulation. In the case of wicked problems, different stakeholders will have different knowledge about this, and will structure the world differently.
- A definition of what constitutes desirable or undesirable change.
- Clarification on the time frame for analysis.

Though rigorous and mathematical, these items are not objective and value-free, and it is important to involve as many diverse stakeholders and experts as possible in the process of framing resilience and developing the model.

Any type of mathematical model can be used to quantify resilience, as long as it gives us a measurement of how the system will respond to the disturbances of interest. The notion of desirability then allows us to quantify the degree of improvement or deterioration that will occur and thereby quantify resilience. Accordingly, resilience has been decoupled from basins of attraction, or from any mathematical artefacts of a specific type of model. Whether we have change that is sudden and shocking or slow and gradual, whether we have basins, attractors or not, we still want to be able to steward towards desirable and away from undesirable system features – we still want to be resilient.

Whatever type of mathematical model is used, its development should be embedded in an appropriate participatory process for framing resilience and making explicit the world view which underpins the modelling assumptions to all of those who will use the model for decision-aiding.

8.

Researching Resilience

8. Researching Resilience

8.1. Introduction

This chapter applies the operational framework presented in Chapter 5 to the design of research programs concerning resilience. It describes the Systemic Integrated Resilience and Adaptation (SIRA) Research Program (CCAFS, 2014b). The author designed the SIRA program, created a successful proposal for funding through the CGIAR Climate Change Agriculture and Food Security Research Program and became its Principal Investigator. The SIRA program began in January 2012 and runs until December 2014.

The SIRA program is fundamentally concerned with the resilience of smallholder farming communities to environmental change, with a specific focus on climate change. The program examines the integrated social, economic, political and environmental systems in which these farmers are embedded. It aims to co-identify and support appropriate actions at multiple levels within these systems according to the principle of subsidiarity and adopts a critical approach to systems and their boundaries. It draws together diverse forms of knowledge generation and sense-making from across disciplines, sectors and social worlds towards the interrelated goals of climate resilience, sustainable development, environmental management and food security.

The SIRA program was motivated by concerns for global food security in the face of climate change combined with multiple other stressors now and in the future. Food security underpins the stability and prosperity of entire societies, as evidenced by food crises around the world. Global food systems are facing unprecedented and ever-increasing pressure from climate change and environmental change more broadly. The resilience and adaptive capacity of food systems depends upon a complex web of social, economic and environmental factors such as population growth, social capital, education and access to information, equity, community or household structure, political stability, strength of institutions, conflict, poverty, economic variability, natural resource management, biodiversity, the adaptive capacity of ecosystems, geographical conditions, and so forth.

Accordingly, the identification of socially and culturally appropriate and endorsed resilience and adaptation strategies, which balance human development objectives with environmental management objectives in a changing world, has become an urgent necessity. Furthermore, ways of integrating these strategies across disciplines, sectors and scales is also crucial in order to avoid conflicting strategies or approaches that ultimately lead to unexpected negative consequences down the track. In short, we need a systemic framework for integrated resilience and adaptation planning.

The focus on smallholder farmers comes from the knowledge that the majority of the poorest and most vulnerable people in the world are smallholder farmers. According to the International Fund for Agricultural Development (IFAD), 'there are around 500 million small-holder farms in the developing world and they are home to some 2 billion people, including half of the world's undernourished people and the majority of people living in absolute poverty. In much of Africa and South Asia, small farms still account for the largest share of agricultural output'(Hazell and Rahman, 2014).

This chapter will describe how the operational framework presented in Chapter 5 was applied to the design and implementation of the SIRA program. The chapter describes what worked, what didn't work and why, in terms of achieving the goals of critical interdisciplinary resilience research. Lessons learned for the design and implementation of resilience research programs and interdisciplinary research programs, in general, are put forward together with dimensions for further thought.

8.2. Applying the Operational Framework to Research Program Design

This section reviews briefly some of the key dimensions of the conceptual framework presented in Chapter 4 and the operational framework presented in Chapter 5 that were used in the design and implementation of the SIRA research program.

The conceptual framework for resilience presented in Chapter 4 demonstrated that, in order to meaningfully explore, characterize, measure, or build resilience or adaptive capacity, resilience 'of what, to what, from whose perspective and over what timeframe' must be specified. Since taking a resilience approach involves acknowledging the fundamental interdependence and interrelatedness of all things, being holistic in our research is not possible, since we cannot have a God's eye view of everything. Thus we are forced to make judgements about what to include and what not to include in our analyses. These decisions are normative and depend on the inquirers' purpose, values, education background, institutional setting and many other factors. What constitutes desirable change within those boundaries is also clearly normative and notions of improvement and detriment differ between stakeholders. How system boundaries and measures of success or improvement are defined will completely determine what is interpreted as resilience or adaptation versus vulnerability or collapse. Resilience is not objective.

A great deal of systems thinking literature deals with these issues of interconnectedness, a quest for holism, and inevitability and subjectivity of system boundary judgements. Systems thinking has wrestled with these issues for 40 years longer than the current dominant resilience community [1], which today has still not acknowledged these issues (this is one of the contributions of this thesis). Consequently, systems thinking literature contains a wealth of rigorous theoretical and methodological tools for dealing with these challenges that resilience thinkers can draw upon.

Critical Systems Heuristics (CSH) provides a framework for systematically critiquing assumptions about system boundaries together with notions of desirability, as well as who should be involved, and how(Ulrich, 1983). Chapter 5 adapts CSH for framing resilience. As was the original intention with CSH, this framework is intended to be applied individually by researchers and practitioners and also dialogically in group processes. According to Ulrich, by surfacing the normative content of system boundary judgments, CSH creates a 'symmetry of helplessness' between experts and affected citizens, freeing the affected from the impositions of the involved(Ulrich, 1993).

[1] Embodied by the Resilience Alliance, associated institutions such as the Stockholm Resilience Centre and also represented by huge international conferences, such as Resilience 2014 (which repeats every few years).

Systemic Intervention builds on CSH– it takes up where CSH leaves off. The realization that we can explore different boundary judgements and the values associated with these legitimates the notion of theoretical pluralism: drawing on multiple theories depending on our purposes, which, in the case of the SIRA program, include social, economic and environmental dimensions. Different theories assume different boundaries of analysis. If we can decide between different possible boundaries, we can also draw upon a wide range of theories. Different methods make different theoretical assumptions. Thus, exploring different boundaries will imply exploring different theories and different methods(Midgley, 2000). Also, there is no method that can do everything and triangulating our data through the use of multiple methods is an important form of research quality control in this context.

The key aspects of Systemic Intervention that have been deliberately embedded into the SIRA program are:

- Boundary critique using the adapted CSH given in Chapter 5.
- Theoretical Pluralism.
- Methodological Pluralism.
- Dialogical as well as instrumental reason.

Accordingly, the SIRA program is designed to apply multiple lenses, multiple theories and multiple methods to the same topic: the resilience of small-holder farming communities. The program involves a core team of five researchers and a support officer. Four of the researchers represent social, economic, political and environmental lenses. The fifth researcher facilitates the integration of the lenses through shared participatory action research, and through multiple forms of integration activities and workshops within the core team, and together with stakeholders and subject matter experts. The support officer provides practical and emotional support to the team members throughout all activities, and documents the entire process including intra-team dynamics.

Every member of the SIRA team works together with each otherand with smallholder farming communities, community-based organizations, multiple levels of government from local to national, and non-government organizations at multiple levels from local to national, in order to frame resilience and adaptation, and to work together to build the capacity of smallholder farmers to absorb, recover from, adapt to and benefit fromenvironmental change. When undertaking participatory resilience framing and building activities, the SIRA team adopts a strength-based approach, seeking to build on what exists and empower stakeholders for continued improvement in their own terms.

The SIRA team was requested by CCAFS to ensure that each field program was not only an isolated capacity development exercise for the particular communities involved in the study, but that the team must look for scalable, replicable and transferable approaches to building resilience and adaptive capacity of smallholder farming communities. Accordingly, the program was structured to incorporate a process for drawing out scalable, replicable and transferable features of the research. The structure of the SIRA program is shown in Figure 8.1.

The overarching focus of each of the lenses is as follows:

- Political lens: Who has the power to do what about resilience and adaptation of smallholder farmers? This includes questions about the role of policy (multi-scale) in resilience and adaptation of smallholder farmers. One key question is, how can policy best support resilience and adaptation of smallholder farmers?
- Social lens: What is the impact of different forms of social differentiation on adaptation of smallholder farmers? This includes the questions, what social, cultural and gender specific barriers and opportunities exist for adaptation of smallholder farmers? How do particular adaptation strategies differentially affect different social groups?
- Economic lens: What networks exist for transfer of funds to support adaptation of small-holder farmers (top-down and bottom up)? This includes the questions, how can equitable, ethical and efficient transfer of funds be guaranteed? How can it be ensured that funds reach those most vulnerable?
- Environmental lens: What is the environmental impact of the various strategies for resilience available to different actors at multiple levels in the linked social, economic and political systems in which small-holder farmers are embedded? This includes the questions, what is the environmental impact of adaptation policy? What is the environmental impact of the tools and strategies currently available to farmers? How can environmentally sustainable adaptation of small-holder farmers be guaranteed?

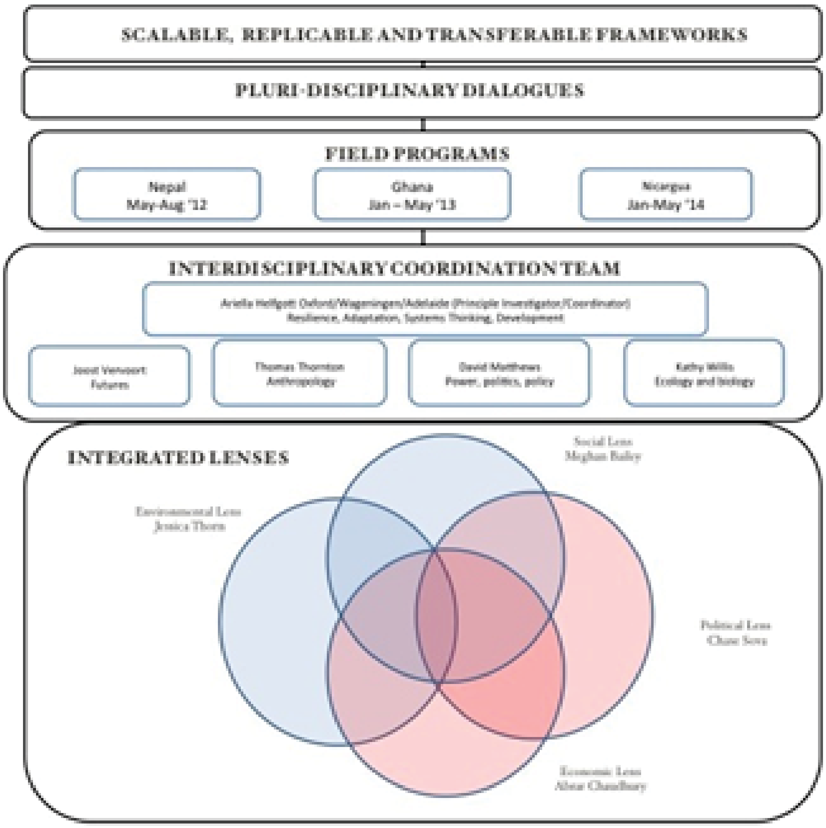


Figure 8.1. Structure of SIRA Research Program.

Each of the four lenses undertook this research program as a way to gain their PhDs. As Figure 8.1 shows, there is broader involvement of senior academics through the formal supervision of the four PhD students.

All team members are in the field together conducting shared research activities, analysis and boundary critique as well as individual research activities. Dialogical processes and systems tools such as rich pictures and influence diagrams are used to integrate analysis across the lenses. The SIRA program adopts a grounded-theory approach (Glaser and Strauss, 1967)to implement integrated field research studies that are followed by in-country and Oxford-based pluridisciplinary dialogues. Through these iterations the team, together with involved stakeholders and subject matter experts, draw out the scalable, replicable and transferable features of the research. The iterative structure of the field programs and dialogues is shown in Figure 8.2.

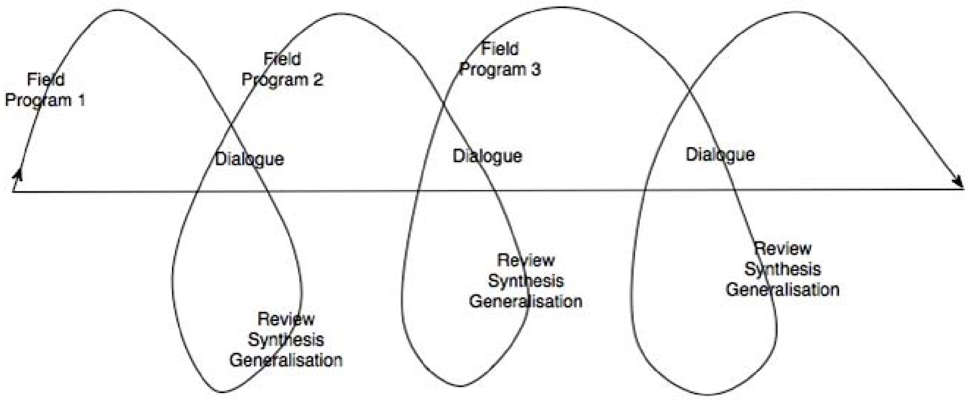


Figure 8.2. Iterative Design of Field Programs and Dialogues.

The SIRA program also aims to build upon and integrate with other CCAFS programs. In particular, SIRA is formally integrated with the CCAFS regional scenarios program: the Principal Investigators of each program participate in both programs as well as other team members and these individuals are responsible for ensuring that knowledge is shared between programs. The SIRA program operates from individual, through household, community, district, regional (subnational) to national level and the regional scenarios program operates at regional (supranational) level. Members of both teams participate in both programs and seek to share knowledge and use products from both programs.

8.3. Critical Reflections

Together, the team successfully applied a range of participatory methods within and across decision-making levels: from household and community, through district and region (subnational) to the national and regional (supranational) levels. These processes included the diagnostic and planning workshop described in Chapter 5, and the farmer exchange and scenario processes described in Chapter 6, as well as other activities including a large-scale multilevel integrated governance workshop, and integration with the CCAFS regional scenarios process. Full details of all of the methods used within and across lenses, including the multilevel governance workshop and regional scenarios process, are available from CCAFS and the author in the form of bi-annual program reports(CCAFS, 2014b). The team directly supported the implementation of community-identified adaptation plans through continued facilitation of ongoing planning and action, seed funding, forging connections with supporting organizations and staying in touch over the course of three years.

As illustrated by the case study example in Chapter 6, the SIRA program had a great deal of success, achieved many positive outcomes on-the-ground and everyone involved learned a great deal. The diagnostic and planning workshop covered in Chapter 5 has been adopted by CCAFS for community level adaptation planning in five regions: East Africa, West Africa, South Asia, South-East Asia and Latin America (Helfgott et al., 2014). It has also been adopted by UNEP for community adaptation planning in the context of protected areas in West Africa (UNEP-WCMC, 2014). The process used and lessons learned in Chapter 6 have been formally included in CCAFS guidelines for the climate analogue tool, including farmer exchanges using the tool (CCAFS, 2012).

As well as the shared participatory action research activities, the individual researchers carried out their own detailed studies within each of the lenses, yielding an almost overwhelming amount of information. There have been numerous papers submitted by the team and, as this is the final year of the program, many are advanced in progress [2]. The challenge is integrating this knowledge across lenses and levels into something both academically rigorous and useful for stakeholders in the countries SIRA works in.

However, the vision of an integrated interdisciplinary team addressing the resilience of smallholder farmers did not manifest quite as imagined. Each of the lenses experienced academic pressure to focus on their PhD individually, and to think about how to differentiate themselves from each other. Though their funding came through CCAFS and the SIRA project, the lenses were institutionally located in academia where they were subject to no performance measures that incentivized sharing knowledge and collaboration. In fact, for PhD students, it seems almost the opposite can be true. Accordingly, the four lenses did focus on their PhDs individually and, over time, collaboration/integration became seen as time-consuming and a burden, which would not help them with their PhD. Knowledge sharing and integration activities then were only carried out, eventually somewhat belligerently, during formal activities required by the project. These activities came to be seen by team members as separate to their PhDs rather than contributing to them through novel cross-cutting insights.

Though all researchers were in the field together, there is a big difference between a group of people going into the field together and saying to themselves, 'How can we work together to parsimoniously collect the data that we need?' compared with, 'How can I individually collect and own enough data to constitute my own individual PhD?'Before the SIRA program began, the author of this thesis knew all of the individuals in the team well;

[2] Each of the PhD students has submitted one or two papers, with two or three more to be submitted by the end of 2014. The author of this thesis has submitted an article based on Chapter 6 and plans to submit four more later this year based on Chapter 5, the Ghana Multilevel Integrated Adaptation Governance (MIAG) workshop, the results integration of the SIRA program with CCAFS regional scenarios process, and one on this current chapter.

she handpicked them for the project based on their quality as researchers, their differing expertise and perspectives and, importantly, based on their strong track record of working collaboratively and preferring to work collaboratively. The evolution of the behaviour of the researchers and the functioning of the team is perhaps telling about the magnitude of influence individualistic academic performance measures can have on people over time.

There are also important differences between what academia needs, what the donor needs and what stakeholders in the country itself need. True to the operational framework, the lenses applied suites of methods to understanding resilience and adaptation of smallholder farming communities. These methods met prevailing academic standards of rigour and novelty; however, only a small number are appropriate, replicable or transferable for government agencies, NGOs and communities in-country, which was a goal of the program [3].

Halfway through the second year of the program, it was already clear that methodological reassessment of the SIRA program was necessary to address issues with integration of the lenses and development of appropriate integrated frameworks, methods and tools for the countries we work in. The original design of the program involved developing and testing our frameworks, methods, tools and results across three regions – Asia, Africa and Latin America. Rather than going to a third region, it was necessary to dedicate time to alternative activities that would allow the cross-lens (and accordingly cross-level, cross-sector and cross-discipline) insights to be realized and translated into useful practical products, while simultaneously contributing to PhDs and reducing pressure on the students.

The development of practical products must be done with stakeholders in each context. The SIRA team realized it was in a position to design and pilot a participatory process, based on its own experiences of developing integrated products and based on the in-country knowledge and contact network gained from the program to date. Accordingly, the SIRA team committed to returning to Ghana to achieve the original integrated goals of the program rather than undertaking an entirely new field program in Latin America. A return to both Nepal and Ghana was outside the temporal and financial budgets allowed by the SIRA program; though CCAFS indicated that, according to the success of the pilot process in Ghana, replication of the process beyond the duration of the original SIRA program was desirable. The revised field programs are shown in Figure 8.3.

[3] While specific adaptations may not be replicable or transferable across locations, agencies or communities, methods for understanding and building resilience and adaptive capacity may be; thus transferability and replicability was a goal of the program, so that local partners may take over the process themselves.

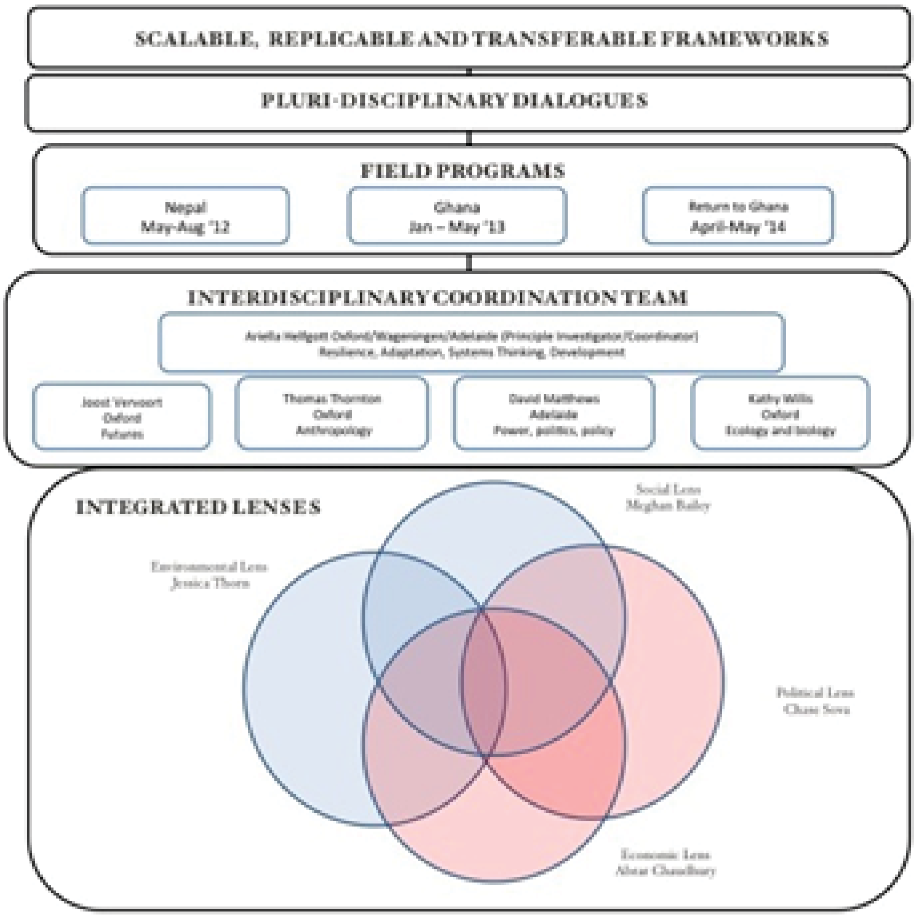


Figure 8.3. Revised SIRA Structure.

Section 8.4 describes in more detail the measures that were implemented to address integration of lenses; as well as co-developing frameworks for integrated multi-actor resilience and adaptation planning in-country. This section aims to discuss the reasons these measures were necessary halfway into the program. The design of the program that placed all researchers together according to the principles of Systemic Intervention, with extensive shared field time, activities and regular dialogical processes, on a common topic, was not enough to guarantee collaboration and cross-lens insights. The reasons for this fit in to three categories:

- Differing incentive structures of academia and practice.
- Challenges of interdisciplinary research.
- Personal and interpersonal dynamics.

Differing incentive structures of academia and practice have already been discussed; the following two points will now be covered in turn. Integrating knowledge across disciplines is fraught with difficulty, since different disciplines have different ontological (the way things are) and epistemological(what we can know about the way things are) foundations;different ways of dealing with truth, complexity, diversity, pluralism;different ways of framing issues, different methods for generating and handling knowledge; different methods for arriving at decisions;different approaches to quality control and rigour; different standards about what constitutes data and evidence; suggesting different types of solutions. All of these differences can make it hard to do interdisciplinary research.

There is a traditional view of the disciplines as each representing branches of our knowledge about the world (see Figure 8.4); and that, if you put them all together you produce the unified whole of the scientific endeavor. However, in practice, integrating knowledge across disciplines doesn't work like this. Because of the differences mentioned above, different disciplines can produce conflicting conclusions and recommendations on the same topic. The knowledge produced by the disciplines does not always fit neatly together; it overlaps in complex and dynamic ways and there are enormous gaps and conflicts.

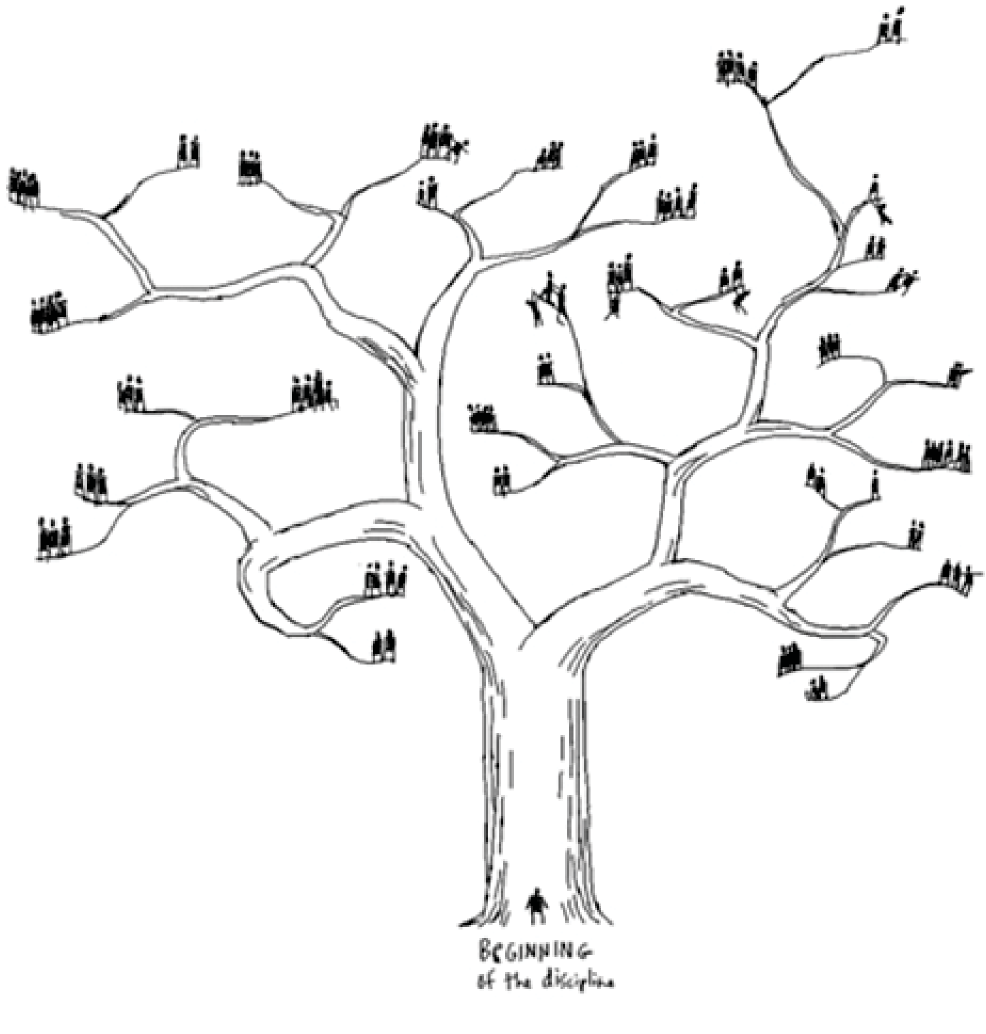


Figure 8.4. Disciplines as Branches of the Tree of Knowledge (Gray, 2009).

Some different positions on truth and knowledge that are relevant to interdisciplinary research and the SIRA program are 'scientific realism', 'pragmatism', 'instrumentalism', 'coherence theories'. Each of these will briefly be discussed in order that these terms may be used in discussion of integrating knowledge across disciplines and the SIRA program.

Scientific realism is the position that the truth implies its correspondence with ontological reality (Tarski, 1969), that science is derived from objective facts and excludes opinions, values and emotions(Bacon, 1620). As Alston put it, "Whatever there is, is what is, regardless of how we think of it"(Alston, 1979).Matthews provides the following list of axioms of scientific realism (Matthews, 2004):

- Scientific laws and theories are verifiable.
- Science is based on objective facts.
- Rigour (mathematical representation) is able to confer objectivity onto subjective observations.
- Scientific laws and theories are falsifiable.
- Scientists are neutral and happy to 'dump their whole cartload of beliefs the moment experience is against them'.
- It is possible to partition science from non-science by some process of inquiry that may be termed 'the scientific method'.
- It is always possible to compare competing theories on purely rational grounds.

All of these axioms have had serious doubt cast on them, particularly during the 'science wars' of the 1990s(Parsons, 2003). Many natural scientists and engineers belong to a large degree to the scientific realist camp.

The way that scientific truth is established in practice more closely matches the pragmatist definition of truth and not the realist one. Charles Sanders Pierce defined pragmatist truth as follows: 'The opinion, which is fated to be ultimately agreed to by all who investigate is what we mean by truth'(Peirce, 1932). This definition corresponds to the process through which scientific truth is established, including peer-review. It does not rely upon correspondence with mind-independent reality; it relies upon social processes of consensus and critique. Implicit in this socially and culturally constructed definition of truth is that it is not fixed and absolute, unlike the realist definition. If we accept that this is the nature of scientific truth, it should not cause chagrin when scientific truth changes over time or when we are faced with the human failings of scientists. The social sciences and humanities acknowledge that establishing truth is a social process.

William James developed a theory of truth known as instrumentalism. James acknowledged that different individuals and communities have different mental schema through which they make sense of the world. Also there is no way an individual or community can shed their mental schema in order to judge whether their ideas of reality are 'truer' than those of another individual or community. Accordingly, there is no hope of assessing closeness to mind-independent reality. James therefore argued that 'truth should be thought of as those beliefs that are useful to those that believe them' (Matthews, 2004).'Any idea that will carry us prosperously from one part of our experience to any other part, linking things satisfactorily, working securely, simplifying, saving labour, is true instrumentally ... ideas become true just insofar as they help us to get into satisfactory relations with other parts of our experience'(James, 1909). An idea will be considered true if it fits in well with the rest of our web of beliefs and helps us to achieve our goals. It also follows from this that truth is relative to the person assessing the usefulness and what is true for one person may not be true for another. James stated this as 'Truth may vary with the standpoint of the man who holds it'(James, 1909). Anthropologists and social scientists generally acknowledge the relative nature of truth.

The coherence theory of truth operates in mathematics and is relevant to conceptual and mathematical modelling endeavours. As long as something is internally coherent and consistent within a given framework that is sufficient for that thing to be considered 'true' within that particular framework. This position rejects the idea of truth as correspondence with ontological reality. As Frank Oppenheimer famously stated, 'It is not the real world; it's a world we made up'(Cole, 2009).

Depending on disciplinary and personal backgrounds, people tend to identify with one of these understandings of truth. However, most people do draw on all of them to some degree at different times and in different contexts. Clashes between researchers can occur when they are entering into cross-disciplinary discussions from very different foundational positions without knowledge of, and respect for, these differences. Such clashes can seriously affect the knowledge generated and the outputs of the research, particularly as these differences are also associated with power.

An illustrative example of these types of challenge in the SIRA program is described below[4]. The environmental lens is concerned with the way agricultural communities depend on their environment and, in so doing, impact on it; and how this subsequently impacts on them, and so forth. This involved collecting extensive data about ecosystem services[5] and about human well-being. The researcher complied a comprehensive list of indicators of both ecosystem services and human well-being, developed practical methods to measure as many of each as possible, simply and cheaply in the field, including clever sampling strategies. Both data sets were collected at plot level, and sampled at landscape scope.

Collection of both data sets in the same location is not enough to establish the interrelationships between ecosystem services and human well-being. In order to establish these links, the researcher and the author of this thesis worked together to map out all known interactions between these indicators according to the knowledge generated in the field, and the data sets at hand. This mapping could then provide the basis for further quantitative modeling and testing. The initial mapping of the relationships between the ecosystem service indicators and human well-being indicators is shown in Figure 8.5. The legend denotes the data sources for each of the nodes. While constructing the diagram,

4 Many examples of this type of difficulty playing out within the SIRA program can be found both across and within lenses; one illustrative example is covered here.

5 Ecosystem services are the benefits that human beings derive from their natural environment.

the researcher noted down the justification for drawing each link and the data available to test the existence of the link. The researcher and the author of this thesis then showed this preliminary diagram to the researcher's second supervisor – who is in a zoology department – and the response was extremely negative. The supervisor expressed concerns that, in drawing the links in this diagram, 'good quality ecological field data' had been mixed with 'perceptions', which was not science.

Many natural scientists are scientific realists, holding the view that through the scientific method they study the world as it is. In this view, 'perceptions' don't qualify as data. The non-quantitative method of obtaining the links in the map shown in Figure 8.5 also qualified as perception or opinion. The supervisor was relieved to hear that the quantitative data collected for both sets of indicators could be used to statistically establish a numerical value for the relationship between any two variables. Some disciplines exhibit a strong preference for quantitative over qualitative information.

The second supervisor is a kind and open-minded person; what she was concerned about was quality control. She understands the quality control involved in collection of ecological field data, as this is her training; however, she does not feel the same comfort with the techniques from social sciences and anthropology used to collect human well-being data, or from systems thinking used to explore linkages – both of which have their own forms of quality control, based in different epistemological and ontological paradigms. This example clearly illustrates that different disciplines have different ideas about what constitutes data and what constitutes science.

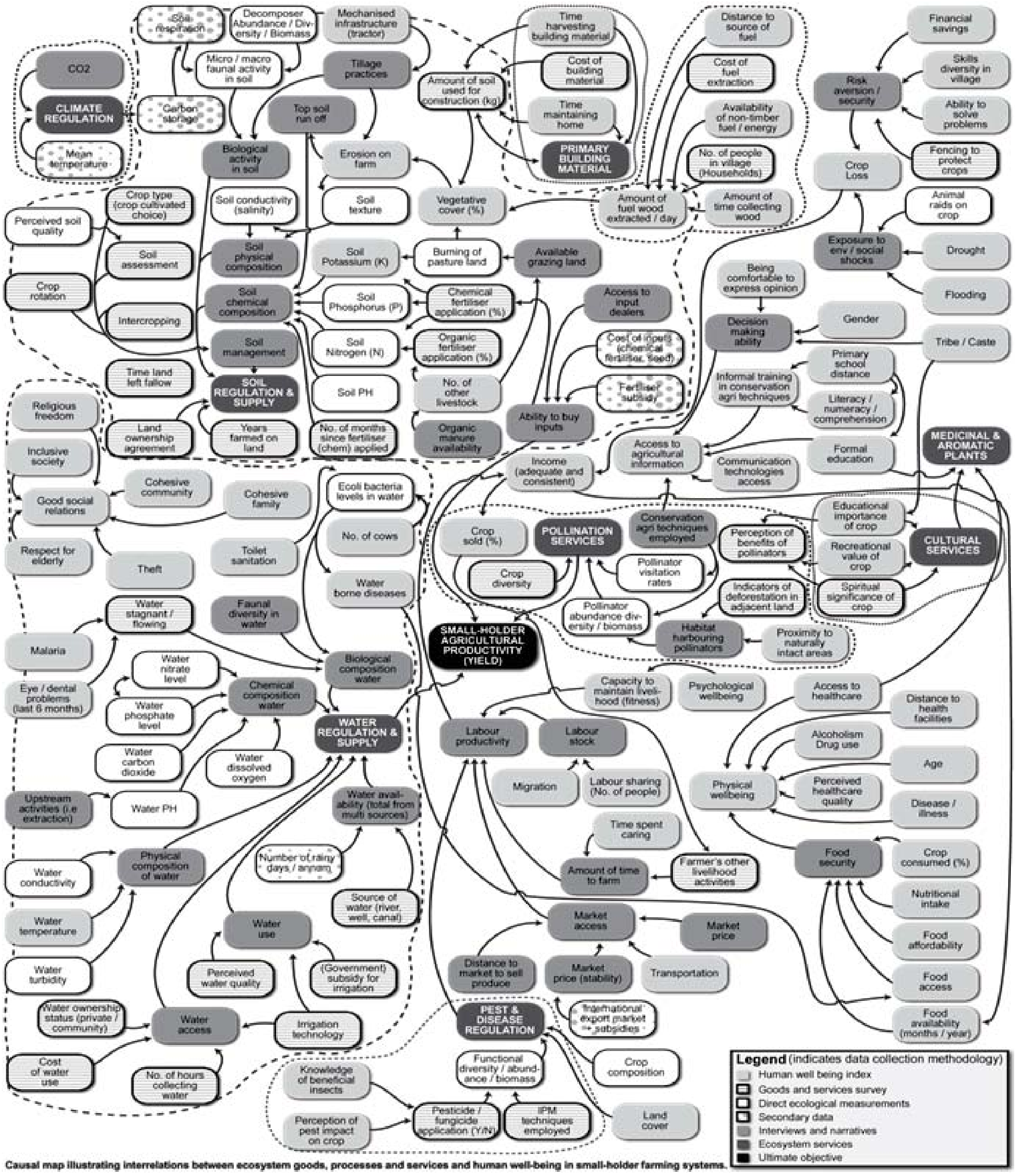


Figure 8.5. Relationships Between Ecosystem Services and Human Wellbeing(Thorn, 2013).

Another factor that strongly influenced the ability of the team to work collaboratively, to conduct integrated research and draw systemic insights from the work was interpersonal dynamics. Perceptions of particular biases held by one group member in the eyes of other group members made them either more or less receptive to the perspectives of that group member, depending on the topic. For example, an individual who regularly attempted to raise awareness of gender-related issues in the field, was perceived as a biased feminist by some team members, making them less receptive to these insights.

Perceptions of agendas relating to power, control or self-promotion had a large impact on knowledge sharing and collaboration within the team. The researchers representing the social and environmental lenses had conflict of this kind and, as a result, both became territorial and opted to work separately as much as they could. During the times that they were mandated to work together on shared group activities, amazing overlaps and synergies were discovered in their work; however, due to territorialism, this was seen as more of an issue than an opportunity. The researchers representing the social and environmental lenses are not publishing anything together and many potential insights about interactions between society and the environment have not been actualized. This stands in stark contrast to the political and economic lenses. The researchers representing those lenses get along extremely well and see the benefits of spending time working closely. This means that the political-economic dimensions of the project are fully integrated, the social and environmental dimensions are not very integrated (some integration has been achieved through shared activities). The remaining connections (political-environmental, economic-environmental, political-social, social-economic) are somewhere in between since, while these researchers don't have a problem with each other, they are primarily working individually on their PhDs outside of formal activities due to the pressures on them in terms of academic incentives and performance measures, as discussed earlier.

8.4. SIRA Integration Measures

In order to address the issues identified in Section 8.3, the Latin American field program planned as the third field program was replaced with the following series of processes:

- SIRA Integration Workshop, Utrecht, The Netherlands, October 2013.
- SIRA Multilevel Integrated Planning Workshop, Oxford, United Kingdom, February 2014.
- Ghana Multilevel Integrated Governance Workshop, Accra, Ghana, April 2014.

8.4.1. SIRA Integration Workshop

The SIRA Integration workshop focused on direct integration of the goals, methods, tools, data sets and insights of the team members. A genuine synthesis of the different lenses could produce collective outcomes with significantly greater impact than any lens in isolation. This workshop aimed to transform the current multidisciplinary situation into a truly interdisciplinary collaboration. External facilitators were brought in so that all team members were participants in the activities including the author, who had taken the role of facilitating integration activities throughout the program previously.

In order to visualize connections between the lenses, the team first had to construct a conceptual space that their individual research could then be projected into. Since the research project is a multilevel, multi-scale endeavour, the team worked to agree on a common scale for the vertical axis. As distinct levels of analysis were identified, it became clear that social and ecological data were collected on different scales. Political, economic, and social data were collected at individual, household, village, district, region, national, and supra-national levels. In contrast, environmental data were collected at below/above ground, farm plot, water catchment, landscape, climatic zone, biome/ecosystem, biosphere, atmosphere, and mesosphere levels. The environmental levels are less strictly ordered than the social levels. For example, terms such as 'landscape' and 'ecosystem' are often used at very different scales. The environmental levels are nested and bounded differently than the social levels. For example, an ecosystem may cross national borders. However, it is possible to approximately align social and ecological data by considering a characteristic scale for entities at each level. This alignment enabled the team to create a vertical axis capable of mapping entities from all four lenses into a single space.

Next, the horizontal axis was negotiated to enable mapping of both the research and its intended outcomes. The following categories were considered relevant: action, effect, method, and data. Action was subdivided to include actions observed currently in the field site (Action: Is) and actions that the research recommended should occur (Action: Ought). The Ought category was not intended to imply that these recommendations should be implemented without consideration of the local desires. Rather, it was simply a place to capture emerging insights from the different lenses in order to identify relationships, such as convergence or conflicting recommendations. The Effect category would contain anticipated consequence of implementing the Oughts, which captures the 'so what' or practical impact of the action research. The Method category includes both methods for data collection and methods for analysis. The Data category documents the type of data each lens collects from the field site.

Each of the participants then mapped the research from their lens into this space using different coloured post-it notes. The author mapped the shared research activities that were part of the project design and not part of specific lenses. The completed map is shown in Figure 8.6 below.

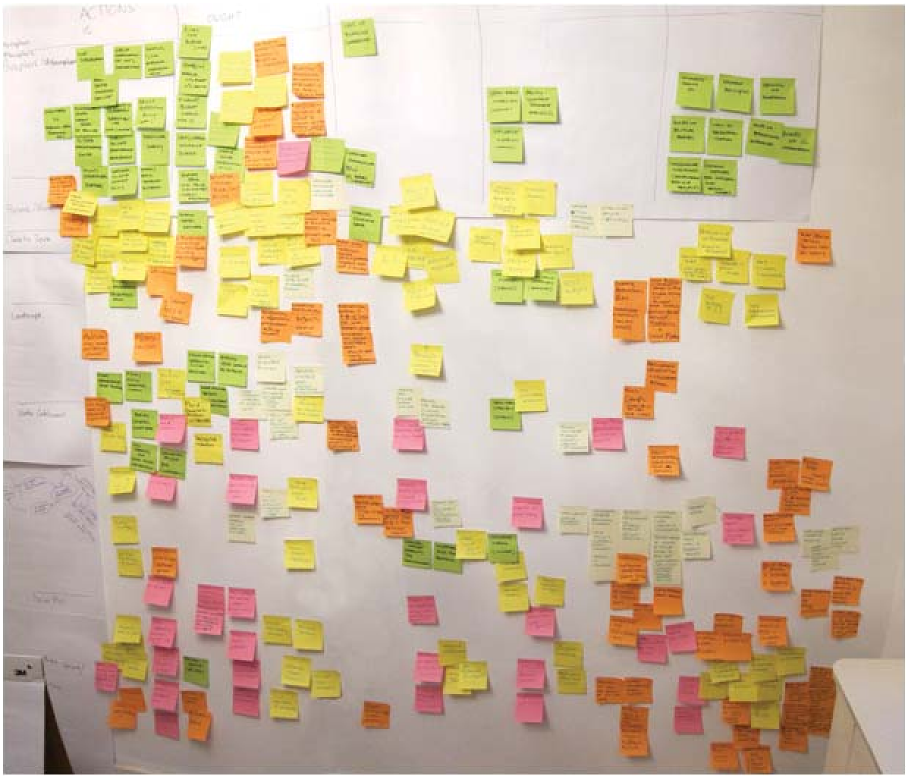


Figure 8.6. Conceptual Map of the SIRA Lenses.

During the mapping exercise, as patterns emerged, a number of insights were identified, some obvious to the team and some more surprising:

- The importance of incorporating environmental/ecological data in adaptation planning;
- A preoccupation with the extension worker bottleneck was preventing other opportunities from being identified;
- The political lens was focused at the national level, with limited penetration below the district level;
- The social lens data and methods were focused at the individual to village levels, but had policy implications at much higher levels;
- The data collected by different lenses at different scales could be useful to other lenses with small modifications;
- The value of mapping all the research activities in one place to externalize information that was previously implicit.

After the map was completed, each participant told the story of their lens. This added depth and context to the post-it notes that were arrayed within the space.

To complete day one, each participant selected one post-it note from each other lens that was different from, yet connected with, their own research. This meant that each pair had two connections to explore between their research. Day two began the work of connecting and synthesizing the individual research. A round-robin format enabled the participants to deeply explore specific relationships with each other researcher. Each pair was allocated 15 minutes per connection to create a storyboard to visualize a way to prototype the connection in the field. The prototype should be cheap, quick and generative (rich in learning potential). In total, 12 storyboards were created. Although these criteria were not strictly adhered to, each storyboard describes a tangible and practical way to synthesize two or more lenses.

For example, the environmental lens has tools to monitor the environmental impact of different adaptation strategies, the political lens has maps of actor networks and power relationships within Ghana. Using these maps, they can work together to identify actors with the interest, power, and resources to contribute to resilience and adaptation of agricultural communities. The pair discussed a user-centred approach to co-designing an approach with these key actors, to incorporate environmental data into adaptation planning. The prototype drawing that accompanied this concept is shown in Figure 8.7.

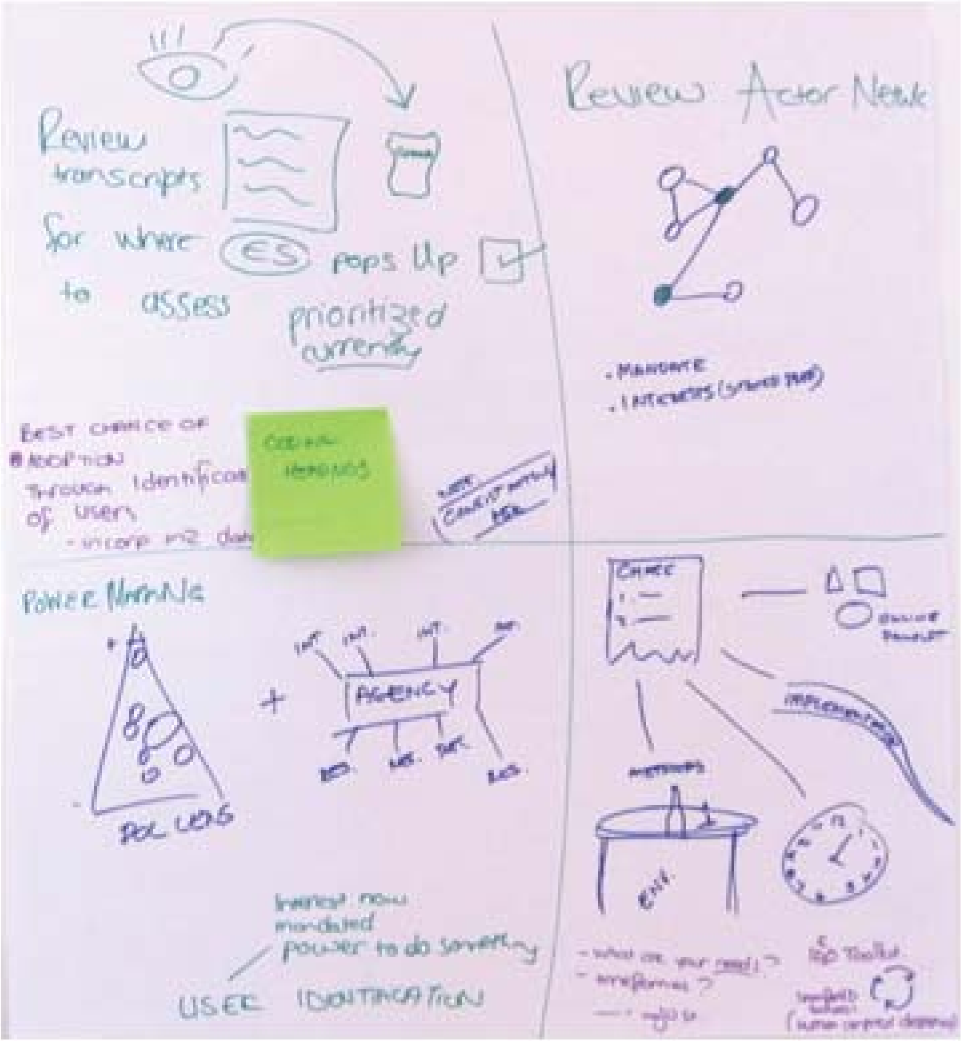


Figure 8.7. Environmental-Political Link Prototype.

The prototyping session delivered a rich set of bidirectional connections between the four lenses. In the final session, the team focused on how all four lenses converge around a common purpose. A simple nested framework was used to organize brainstorming on the commonalities between the four lenses. The framework asked four questions about the SIRA research program: Why? What? How? By Means Of?The populated framework is shown in Figure 8.8 below.

Figure 8.8. SIRA Nested Framework.

The post-it notes from the brainstorming were used to hold a facilitated discussion around the four questions.

This process revealed the following:

- As a whole, the team has collected a phenomenal amount of data.
- A large number of links were identified and it was clear that there are a huge number of unidentified links that could be explored, given more time dedicated to integration.

- The researcher representing each lens was only interested in the other lenses where they could see that it could be a paper they could write or would contribute to one of their chapters.

The process was very exciting and engaging. The team members committed to developing their prototypes and exploring further links prior to the next workshop in February.

8.4.2. SIRA Multilevel Integrated Planning Workshop

As the second workshop approached, it became clear that (apart from the political and economic lenses, who are friends) none of the lenses had spent as much as one minute together since the workshop in October. They had all gone back to desperately writing papers in their bedrooms by themselves. None of the prototypes had been developed or cross-lens linkages explored.

As it seemed the role of 'PhD student' was part of the issue with integration of the lenses, the author suspected it would be helpful to adopt an alternative approach that strategically asked people to take off their PhD hat temporarily, not to focus on their own research (methods, tools, data and so forth) and just to focus on Ghana directly. Simultaneously, the team needed to think about what it would do during the return to Ghana in order to work together with stakeholders from multiple levels of decision-making to develop appropriate integrated management, planning and decision-making tools for resilience and adaptation. Together with the same facilitators that conducted the SIRA Integration Workshop, the author designed a methodology that drew out the knowledge of all lenses into a rich multilevel picture of what is going on in Ghana relevant to climate change, agriculture and food security. The experience of this exercise was then used as the basis for facilitation of the SIRA team designing the methodology that would be implemented in Ghana in April-May 2014.

Accordingly, the workshop served multiple purposes. They were:

- Development of a multilevel rich picture of climate change, agriculture and food security in Ghana based on the integrated knowledge of the SIRA team.
- Exploration of entry points for transformative change to achieve multilevel integration of activities to promote resilience and adaptive capacity of small farmers in Ghana.
- Design the Ghana workshop schedule of activities.
- Indirectly, increase integration between the lenses (political, economic, social, and environmental).
- Explore process design as a research method for pluridisciplinary integration.
- Create a legible methodology to share with development workers and researchers in other contexts.

Progress was made on each of these fronts as documented below. The structure of this narrative has been organized by purpose in order to focus on outcomes associated with each purpose.

8.4.2.1. Multilevel rich picture of Ghana based on the integrated knowledge of the SIRA team

The first day of the design session was dedicated to developing a rich picture of Ghana, drawing together and representing the knowledge embedded in all of the lenses on one diagram. In addition, because the rich picture at multiple levels was selected as an activity for the Accra workshop, a second iteration of rich picture drawing was performed on the second day to map the different levels of the system.

The rich picture is a method from Soft Systems Methodology (SSM) developed by Peter Checkland (Checkland, 1999). According to Checkland, the term 'rich picture' was initially metaphorical, and meant developing a vivid textual description of the problematical situation. But when one group took the idea literally, the SSM facilitators quickly realized the power of simple sketches to illuminate systemic relationships that are not so easily captured in narrative form. The drawing of rich pictures, showing the system elements and their relationships, quickly became one of the most widely adopted soft systems methods.

To guide the rich picture development, the team used a set of guidelines put forward by Armson (Armson, 2011):

1. Rich pictures are not structured in any formal way. This means: don't draw it as a comic strip; don't structure it with a single over-arching metaphor; don't structure it as a timeline or systems diagram; allow the use of any/multiple forms of representation.
2. Words can be used as labels, as exclamations in speech bubbles and in other brief ways, but not as sentences and paragraphs that need to be read.
3. Include relevant observations about culture, emotions, and values, including the emotional climate, social roles, and your own values, beliefs and norms, and personal stuff that may 'get in the way'.
4. Include other points of view.
5. Include a representation of yourself.
6. Include a title: 'A rich picture of the situation'.
7. Include a date.

A key tip here is to make sure there is plenty of activity in your picture. Don't just draw stick-figure people, show them doing something and show some of their context – where they do it. Include resources, tools, equipment, buildings, ideas, dreams, processes and objects. Use metaphors. Show interconnections. Make it rich.

8.4.2.1.1 Combined Rich Picture

The team brainstormed a list of things they knew about Ghana first. These factors are organised into a mind map in Figure 8.9 below.

Figure 8.9. Mind map of brainstorming: What do we know about climate change, agriculture and food security in Ghana?

Then they began drawing together across four A1 flip-chart pads. As they worked together, they explained their pictures to one another and built on each other's contributions. In particular, there were a lot of discussions on how to represent the more abstract information, such as the dynamics of international development, different decision spaces, decentralization, and lack of a culture of collaboration. The rich picture is shown below in Figure 8.10. The team then told the story represented by the rich picture, moving roughly from left to right.

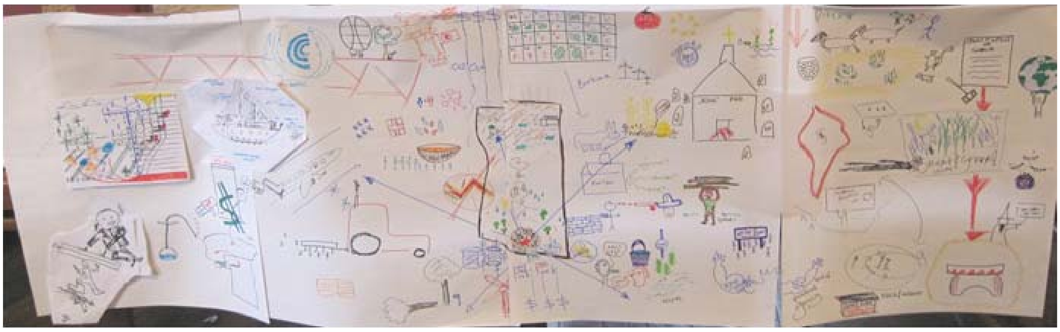


Figure 8.10. Rich Picture of SIRA Team Knowledge of Ghana.

The A4 page inserted at the top left synthesizes multiple elements of the system into a metaphorically structured sketch. The landscape is divided into rural on the left and urban on the right. Between them is an umbrella, which collects resources and redistributes dollars to the people. On the urban side, the environment is structured into boxes. People, who sit in these boxes, have easy access to relatively large flows of dollars, which is why so many people are attracted to the urban environment. In the rural environment, the dollars are much more scarce, and become smaller further down to the village level. Villagers have to run long distances to catch small cents. The red line indicates foreign influence and resource extraction, which is channeled through the cities and into the rural environment.

Below this, a hierarchy of oppression is shown. At the very base, barely visible, is a female baby, male babies are slightly larger, a female bent over from hard labour, while a man rests his foot into her back representing significant gender inequality, the man is himself being oppressed by corporate and political interests. Moving to the right, pictures show a hookah pipe representing Middle Eastern business involvement in Ghana, transportation of goods, partisan distribution of services, corruption (dollar sign walking into the voting booth), a tractor harvesting dollar signs (commercial agriculture, possibly liberating farmers) were drawn. Owners of tractors have a lot of power, as demand is so high they can pick and choose which fields they will plough. Trees are drawn as chopped down to show deforestation.

Above this, the boat represents navigation of policy, a perpetually moving situation continually reacting to natural forces of the wind and the waves. The sails represent tradition and reform, and influence the ability to change the speed of development. The large sail is a patchwork of different types of policies, while the small sail is composed of key people who allow you to navigate through development. Smaller people sitting down on the boat are watching, and may be passive or active in motivating and influencing change. The people below, like smallholder farmers, are rowing and are less visible but continue to maintain a steady course. Pirates are shown as external forces that exploit the resources and threaten the speed of development.

Above the boat, scaffolding represents the framework for international policies on environment/climate change. The United Nations Framework Convention on Climate Change (UNFCCC) logo is also a labyrinth; you go in one end and come out the other, and yet nothing changes.

There is relative clarity at the global level in terms in funding, but drilling down the channels and allocation strategies become blurred and chaotic. At the local level, the pot is empty. There is a geographic bias within Ghana. There is limited budget allocation to the northern region of Ghana. The geographic bias is perpetuated by the feedback cycles shown in Figure 8.11. When a geographic area is a focus of central funding, its infrastructure and resources improve. This enables the area to increase its internal revenue development capacity, due to greater access to markets and cheaper supply of inputs. Areas with higher internal revenue receive a greater proportion of central funding. This positive feedback loop creates a virtuous cycle of rich areas becoming richer. The bottom loop shows how central funding considers areas of highest needs for funding allocation. The areas of highest need are those with the least capacity to produce internal revenue, due to factors such as land quality, geographic isolation, access to quality education, etc. Because their capacity is so low, central funds invested in this area often yield a poor immediate return on investment. This discourages the central government from allocating scarce resources to needy areas in future budget cycles. This negative feedback loop maintains a relatively low level of funding to the neediest areas, preventing them from escaping the poverty trap.

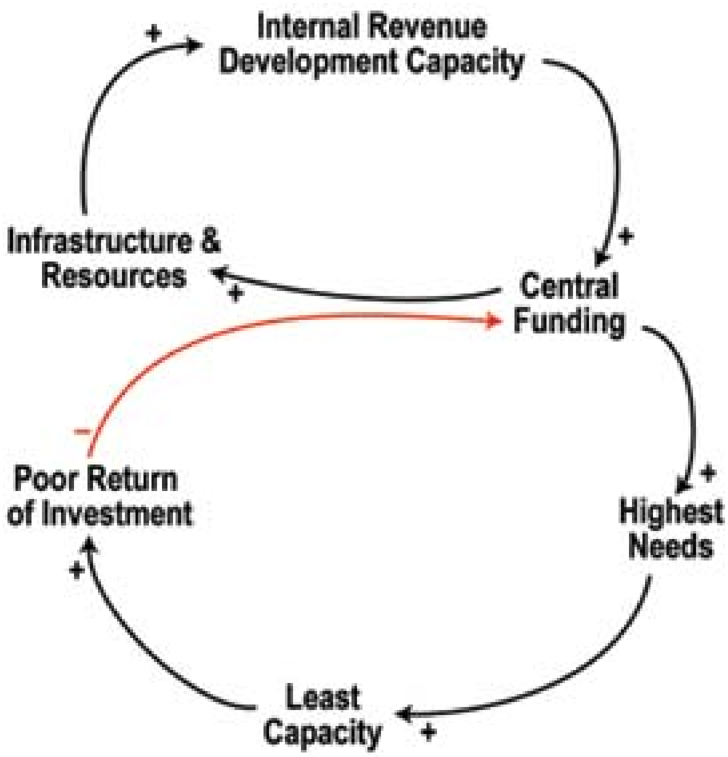


Figure 8.11. Investment and Capacity Development Traps in Ghana.

The oil recently discovered in Ghana has generated a global interest, particularly from China. There are many funding streams into the capital of Ghana, accompanied by a lot of chaos and confusion. Ghana is in flux from a poor to a middle-income country,which means external funding is reduced. The plane to the left represents international organizations' interactions with Ghana – very much a fly-in, fly-out dynamic.

The ludo game represents socialization and community. The pito bowl shows alcohol as both a food and a drug, which is connected with nutrition and has impacts on child development, such as foetal alcohol syndrome. The different sizes of children drawn show differential food access, alcohol-related developmental delays, and socialization factors. Larger male and smaller female icons represent gender inequality through food access and preferential treatment.

The creeping Sahara desert is represented by dotted lines into the northern region of Ghana. The calendar of events above this shows all the commitments (funerals, church, and training) that pull extension workers and other employees away from doing actual work. The Upper East has a similar climate to the Upper West but many more dams in the East, as funding has been directed there.

An important driver for coordination of smallholder farmers is to allow them access to markets. The set of scales represents different levels of the justice system. The diagonal dotted lines means confusion as to which level of justice a person will access, which is largely based on the amount of power they have.

The dry season is represented by less food and different trading patterns. Fertilizer subsidies raise a number of questions. When are they received? Who provides the subsidies? What advice is provided to farmers from commercial interests?

Language is often a barrier in the Upper West. This is represented as 'lost in translation' – two men are talking to each other in different languages. Above this, a man with a gun represents military and law enforcement influences. Ghana is considered a reasonably safe country.

Jesus' pad illustrates the importance of religion, and includes speaking in tongues. Infant mortality is represented by the drawings of tombstones surrounding the church. To the right of this, the Constitution of Ghana flows down to the traditional stool with Gandalf saying, 'You shall not pass'. The stool represents traditional governance, which sometimes ignores or defies the governmental policy. The postcard in between these images represents the international perception of Ghana as a middle-income country with newly discovered oil resources. The oil is seen as a plus but is also leaking off the postcard, creating uncertain consequences.

To the left of the oil, South America provides finances within Ghana for infrastructure. Interaction between smallholder farmers and commercial farmers is drawn to the right of South America. Smallholder farmers migrate to work for commercial farmers during dry season. This provides some opportunities for learning; however, the techniques are so different that there is little knowledge transfer. A muscle man with disproportionate muscles shows international donors vs. local perception. Irrigation needs are represented by a bucket of water in the dry season and the slowdown of work within the dry season. Crop loss occurs due to livestock, pests, and soil erosion. Above Jesus' pad, the Oxford logo shows the research team as part of the situation.

The stories the team told, as they explained the picture, demonstrate just how rich the picture is. It was not intended for any external audience, but rather to enable the team to have a reflective conversation. The team reflected on relationships between the components that were not represented in the picture. Were the team to draw in all the relationships, the rich picture would become an unintelligible tangle of lines. A future iteration of the rich picture could synthesize and distil the elements, allowing the elements to be arranged and linked in a way that better shows their interdependencies. However, this first iteration was intentionally unstructured and made no effort to reconcile different perceptions and worldviews.

Another question the team reflected on was: what is missing from the rich picture? In spite of its complexity, the team identified many things they knew about Ghana that were not represented. The following concepts were missing:

- Fatalism in the district.
- Implementation deficit.
- Drinking water.
- Cooperatives.
- Lack of culture of cooperation.
- Sustainability vs. production culture.
- Polygamy.
- Multilevel civil service.
- Ghanaian perception of Ghana.
- Impact of middle-income label.
- Nepotism.
- Tribal vs. national identity.
- Education in English.
- Quality of education is so poor.
- Hiring freeze.

In addition to listing these, the team asked why in particular these concepts were not included. Are they more difficult to draw? Are there gaps in the team's knowledge? Are they perceived as less important?

The team also reflected on how much of the rich picture was anecdotal vs. empirical. Other methods tend to try to remove personal experience, perceptions, and anecdotes, but the rich picture encourages the researchers to represent and openly discuss these more subjective elements of appreciation.

8.4.2.1.2 Multilevel Rich Pictures

Rich pictures were also used to map Ghana systemically at different levels. Three levels were chosen for analysis: Village, District & Region, and National (see Figure 8.12 below). The team felt the rich picture would be more useful than more formal systems mapping approaches, because it presented a lower barrier to participation.

Because the rich picture provides so little structure, the three levels were mapped out quite differently. The aesthetic differences between the village and national levels are particularly striking. The village is colourful and chaotic, and contains imagery of people and tangible objects. The national level rich picture contains mostly organizational structures, policy documents, and frameworks, all drawn in black and white. It is very ordered and masks the human dimension. This may merely reflect the cognitive preferences of the team members sketching each level. However, it may also capture important differences between the experiences of interacting with different levels of the system.

Figure 8.12. Rich pictures of Ghana at National (left), Regional (Upper Right) and Local (Lower Right) Levels.

Village Level

The village level depicts mud houses, dust and many babies. A locally brewed alcohol, known as 'pito', contributes to developmental delays but also to low educational outcomes including low literacy and numeracy. Education and products for safe sex and family planning are not available, which relates to gender and gender inequality as well as fertility. Pito is also connected to social issues, production, nutrition, and represents unity, which the communities are proud of. Unity is embodied in functional work, mutual reciprocity, building homes. Pito is an important agricultural crop, and is involved in many rituals. The Chief's house is a feature of the village. People going to market day relates to their crop production and community activities, social safety nets and whether they have nutritional deficiencies in times of need, which relates to poverty – an empty bowl. Men have access to more money than women, which impacts gender inequality and, accordingly, nutrition. The police offer certain forms of protection, though justice is unequally accessed. Other features shown include challenges in access to water, hand irrigation by buckets, transport to markets on dusty roads, ancestral inheritance of land, some owned by individual families, cultural heritage, tools, agricultural knowledge, social structures and social safety nets.

District/Regional Level

This picture describes the entire Northern region of Ghana. There are major infrastructure differences between East and West as well as physical differences. Previously, the East received more capital and dams due to World Bank schemes. The soil is quite similar in the East and West but more development efforts and more of a culture of cooperation exist in the East. Tourism, hills, tomato industry, canning factories, better road access to the south and international market access exist in the Upper East but not in West. There is a major disconnect, east to west and west to south, due to road infrastructure. There is a major trend of seasonal migration south to cope during the dry season. The Upper West contains cashew nut, illegal alcohol trade and mango. In Tamale there are many NGOs. There are many projects going on and lots of funding, but this is not well connected to the district of Lawra or the village level. Decentralization is slow; many resources are still controlled in Accra. There are many important decision-makers in the regional centres of Tamale and Wa, but they are disconnected from Lawra and surrounding villages. The team experienced surprise in Accra and Tamale that we visited Wa and Lawra (flights are only to Tamale and the roads are bad). There is a lack of extension services, brokers (region-national disconnects, physical access, language, knowledge), and clear lines of finance for climate change.

National Level

According to the rich picture, everything climate-related falls to the UNFCCC. Ghana is an emerging economy – any change in status has implications for funding and programs. Ghana's long-term development priorities relate to industrialization and the private sector, particularly in the development of oil and gold. Agricultural sector investment has fallen. There is investment in large-scale cocoa production. There is tension between food security and cash crops: cocoa, palm oil, cashew and mango. Policies are associated with specific agencies in the picture. The Ministry of Local Governance has been included to represent decentralization of yearly planning. Long-term planning still takes place in the ministries. Ghana does possess financial ability and administrative authority. There is a functional and organizational assessment tool to monitor district level performance. Donors who want to see return on investment have a large influence. To address climate adaptation, there are movements to organize people into multi-stakeholder groups within each sector and across multiple sectors. Politics has a major impact on climate resilience and adaptation, agriculture and food security. Ghana is a highly political country. Political manifestos have influence on the national development program. The National Development Planning Commission is an independent body with short-term, medium-term and long-term goals. However, these goals can be displaced by short-term manifestos, which don't address climate change. The winning political party is allowed to assign a District Chief Executive (200 districts), answerable to the central government. Administrative and financial decentralization is occurring but the arbiter directly links back to the political power. The University of Ghana is a well-respected and established institution. Other tools that are represented include: West African crop improvement program, International House, regional and continental influences, ECOWAS common agricultural policy, fertilizer subsidies, declarations – e.g. need to dedicate 10% of budget to agriculture. There is a buffer stock program – the government will buy a percentage at fixed price for food security. Ghana also has a public-private partnership policy.

Based on this exercise, the team decided to make several modifications to the activity prior to the Accra multilevel workshop. It was decided to map the system at five levels instead of three: Village, District, Region, National, and Global. It was also decided to add a minimal amount of structure to the rich-picture development process. This was partly to ensure the five rich pictures would nest geographically, so that when they were brought together it would be easier to make connections between them, and they would be oriented consistently on the page. It would also make it easier for participants to get started on their rich picture if they could add actors and entities within a geographically defined space.

The framing question would also add slightly more structure by calling attention to specific entities to map. For their first rich picture, the team had used the intentionally vague question: What do we know about what's going on in Ghana. For the Accra workshop, the team refined this to: At your level, draw the context, tools, challenges, and sources of pride that are relevant to agriculture and climate change.

The team experimented with using coloured string to make connections across the levels depicted by the rich pictures (see Figure 8.13). Green string represented pathways between entities at different levels, while red string represented disconnects. The main pattern the team identified was that most links from the national level were green, but most links into the village level were red, showing a lack of penetration of services down to the village. While not surprising, the visual depiction of this trend was powerful.

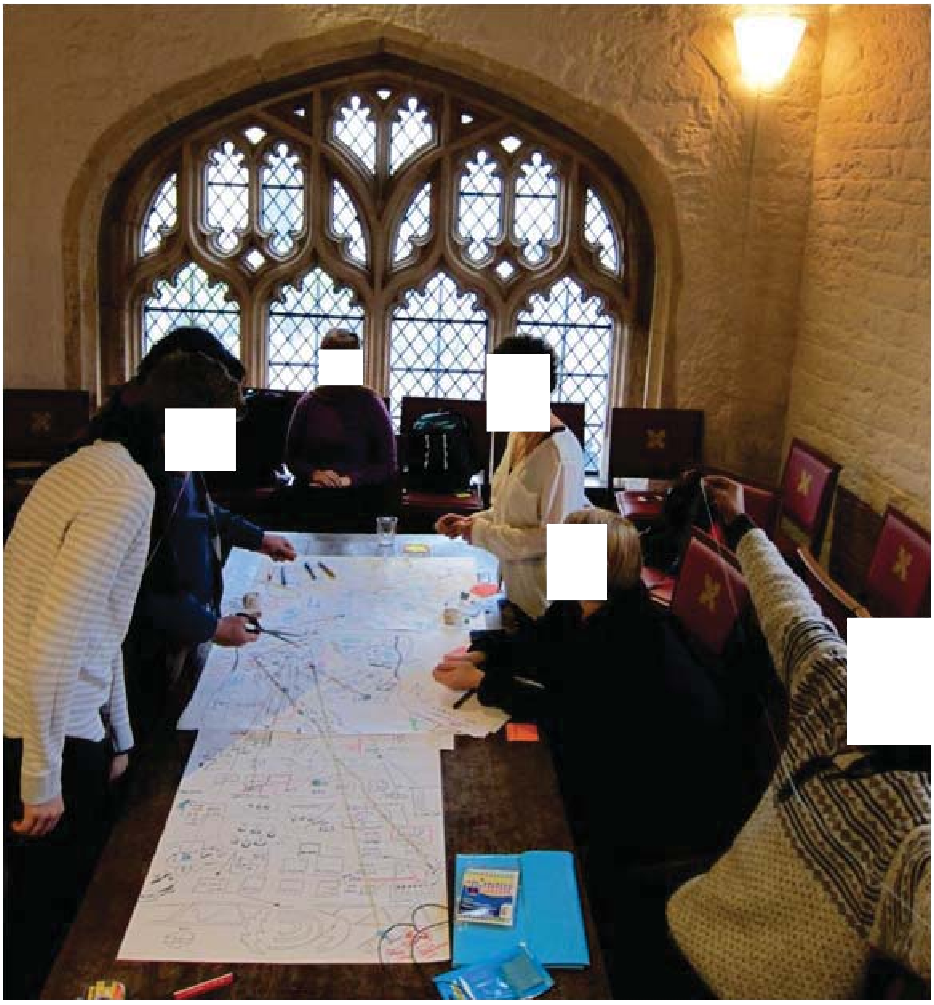


Figure 8.13. Adding Pathways and Disconnects Between Levels.

The use of string was partially effective in showing relationships between levels, but team members suggested several innovations to improve on the technique. If black and white photocopies were made of the rich pictures, the pictures could be joined together and coloured lines could be drawn onto the photocopies with thick markers. A three-colour traffic light theme could show working connections (green), partial connections (yellow), and missing connections (red). The use of photocopies would allow the participants to be split into five themes to map connections on the same set of underlying rich pictures. This would then allow the research team to analyze patterns in the connections identified across themes.

The team did not attempt to come up with solutions to disconnects identified between the rich pictures. The team did not want to prescribe solutions from outside Ghana; their role was to convene and facilitate a workshop where Ghanaians would choose how to respond to the identified challenges. However, to facilitate a large group of approximately 50 participants, it would be useful to identify broad themes within which solutions might fall. This would allow the participants to improve cross-level linkages in areas focused thematically, rather than by existing departmental boundaries.

A brainstorm and clustering exercise was performed to identify the themes (see Figure 8.14 below). The final themes were:

- Land and Water Management
- Agricultural Knowledge Management
- Nutrition, Health and Basic Education
- Markets and Finance

This was a challenging exercise, because the team was aware that the themes would frame the responses that participants would focus on generating. The possibility of letting the themes emerge from the Accra workshop discussions was considered. However, this would introduce a number of risks. Reaching agreement on the theme labels was contentious and time-consuming, even within a small team of researchers who had worked together for years. If it took us two hours to agree on themes, in a group of 50 strangers, it could take all of the time allocated for generating actions just to converge on the thematic areas. Emergent themes might have very different scopes and interest to participants, leading to unbalanced group sizes. Some participants may advocate for a theme to pursue their narrow self-interest. Therefore, it was decided to develop the themes in advance to be as broad as possible, and to allocate participants to themes to ensure that each theme had equal numbers of participants. Team members then selected a theme for which they would be responsible for developing framing questions and examples, and which they would facilitate.

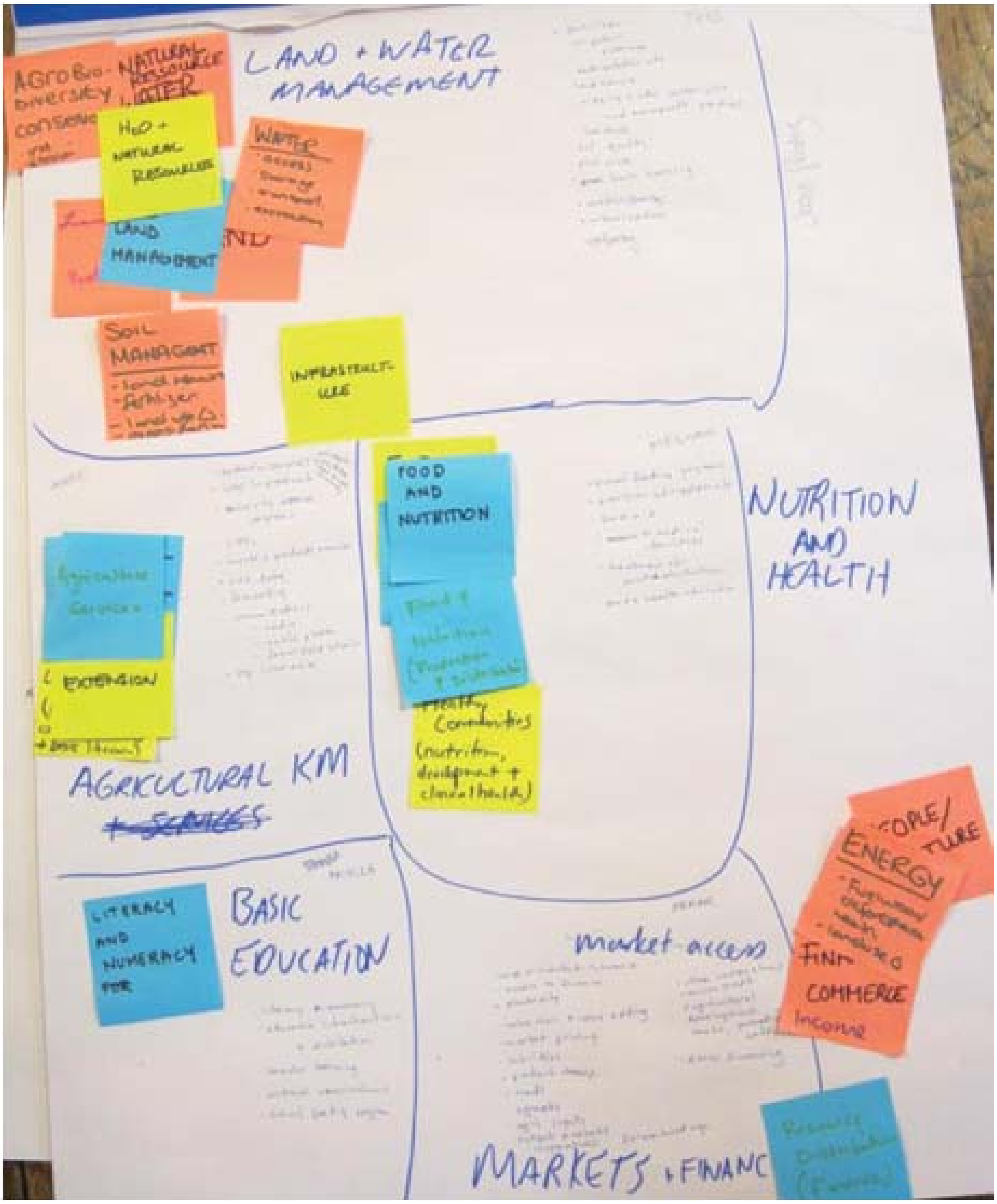


Figure 8.14. Brainstorming and Clustering of Themes for Ghana Workshop.

Producing an internal multilevel framework enhanced the SIRA team's preparation for the Accra workshop. By performing a virtual walk-through of key activities, they could better anticipate participant confusions, and think of responses to help participants when they became stuck. The framework produced by the research team is intended only for internal purposes, and should not be seen as authoritative.

8.4.2.2. Integrating Across Lenses

The author hoped that, by bringing all four lenses together to focus on an integrated framework for Ghana, new connections would be formed between the lenses as a by-product. This worked very well. The rich pictures drew together the perspectives of all lenses for each level, and on one combined diagram. Various connections were established during this process; for example, as the team created the rich picture of Ghana at the District & Region level, the environmental lens explained the historical political significance of Tamale in the rich picture, which led to the political lens recognizing connections with the results of his political lens research.

8.4.2.3. Research by Process Design

At the same time as the team is trying to improve collaboration in Ghana, team members must themselves collaborate better if they are to create a truly integrated framework for climate change adaptation. As mentioned, the first systemic design workshop focused directly on the challenge of integrating the lenses. The second systemic design workshop focused on designing a multilevel workshop on climate change adaptation and agriculture. Integration between the lenses occurred incidentally as participants worked together on a common challenge. In the final reflection from the second workshop, the team reported that this was one of the best times the SIRA team worked together as a team.

The four-day workshop to design the Ghana Multilevel Integrated Governance Workshop helped to prepare the team for their facilitation challenge. It provided the team with an opportunity to iteratively develop a rich picture and construct an internal multilevel integrated framework for making sense of Ghana. Working together on a common challenge related to their shared research interests has provided opportunities for increased integration between the four lenses. The team adopted a novel approach to designing the Accra multilevel workshop, which is itself a contribution to knowledge. Finally, by capturing the process visually and in narrative, the team invites other development workers and researchers to learn from our experiences. The ultimate success of this workshop depends on how well the Accra multilevel workshop achieves its intended outcomes, and whether this success is replicated in Ghana and elsewhere around the world. We will continue to assess the impact of this event as its implications unfold.

8.4.2.4. Making the SIRA Integration Method Legible

Documenting the process of these workshops, as well as their outcomes, is essential for making the SIRA methodology legible to development workers and researchers. The SIRA project has attempted to orchestrate activities that, as far as the author knows, are entirely novel. Convening stakeholders from five separate levels of a situation to work together systemically on improved collaboration across levels is extremely rare, if not unprecedented. Yet it is exactly this type of approach that is needed to take on multi-scale complex challenges such as climate change adaptation. To the extent that SIRA is successful in achieving lasting positive change in the regions in which it has been applied, there will be a demand to scale up the approach and apply it in other contexts.

This Chapter contributes to the legibility of the SIRA methodology by capturing the narrative of how the team designed the Accra workshop. It complements SIRA project reports.

8.4.3. Ghana Multilevel Integrated Adaptation Governance Workshop

The CCAFS SIRA Program in partnership with Ghana's CSIR jointly undertook a program of Multilevel Integrated Adaptation Planning aimed at overcoming disconnects in the flow of knowledge, experience and resources across levels from household, district, region to national, in Ghana's climate adaptation regime. This process involved an intensive sequence of bilateral meetings and multi-lateral focus groups within decision-making levels in the lead-up to a major Multilevel Integrated Adaptation Governance (MIAG) workshop. The MIAG workshop was held at the Ghana Institute of Management and Public Administration (GIMPA) Executive Conference Accra, Ghana, 14-16 April 2014.

The workshop brought together key actors and decision-makers from household, district, and region to national levels, focusing on the Upper West region of Ghana, to co-identify opportunities for greater alignment of adaptation initiatives and improved flows of knowledge and resources across levels, in order to maximize the efficiency and effectiveness of climate resilience and adaptation in Ghana.

Participants travelled from Orbili, Lawra, Wa, Tamale and across Accra for the workshop, shared life experiences and created a mutual understanding of the processes involved in climate change adaptation from each of their perspectives. This shared understanding and the collective knowledge of all participants formed the basis of integrated multilevel resilience and adaptation planning activities.

The workshop was spread over 3 days. Day 1 is dedicated to generating a deep understanding of the different contexts, scopes, scales, challenges, limitations, opportunities and tools that adaptation actors and decision-makers are working with at different levels. Day 2 is dedicated to understanding how adaptation-relevant knowledge and resources flow across decision-making levels, and plans are developed to improve the efficiency and effectiveness of adaptation in Ghana by improving alignment and flows. Day 3 tests the plans against key uncertainties identified in CCAFS West African Scenarios Process, develops robust plans and makes these plans concrete through the specific assignation of responsibility, accountability and time frame. This sequence is shown graphically in the Visual Agenda for the workshop provided in Figure 8.15.

The full program for the workshop is provided below, as are the details of each activity.

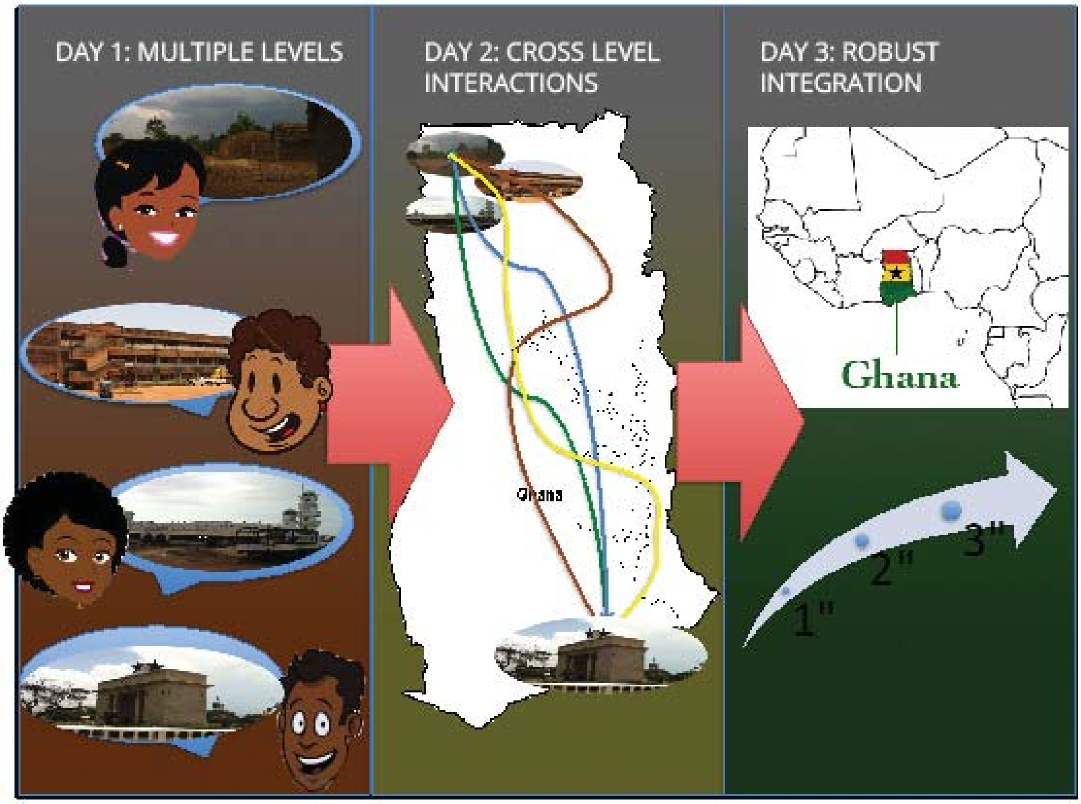


Figure 8.15. Visual Agenda for Ghana Multilevel Integrated Governance Workshop.

8.4.3.1. Activity Descriptions

Table 8.1. Summary of workshop activities and timeline.

Time	Activity	Grouping	Outcome
Day One			
	Speed Meeting	2 Concentric Circles	Establish a safe place of acquainted people to facilitate the next activity
	Narrative-Based Situational Assessment	Multilevel Breakout Groups	Develop deeper understanding of the context that others are working in
	Rich Picture	4 Levels	Visualise basis for connecting levels
Day Two			
	Connecting Levels	4 Themes	Visualise areas for action
	Responses Activity	4 Themes	Key considerations for NCCP and NCCAP implementation Improved cross-level collaboration
Day Three			
	Scenario Stress Testing	4 Scenarios	Stress-tested plans list of additional actions
	Taking CACIT Opportunities (Allocating Action)	4 Themes	Develop operations that are robust to future uncertainties AND create ownership of tangible steps to improve multilevel coordination
Closing Session			

8.4.3.1.1 Speed Meeting

Participants are arranged in two concentric circles so that people are facing each other in pairs. The outer circle will move around the inner circle to allow each person to meet a new person every 1-2 minutes. During the 1-2 minutes participants are facilitated to quickly get to know the new person according to prompts called out by the facilitator. This process continues for roughly half an hour enabling participants to meet at least 15 new people each and generating familiarity and fun within the group.

The specific objectives of this activity are for participants to:

- Get to know each other
- Network
- Learn something new

- Feel safe and valued
- Build empathy
- Establish friendships

  This activity serves as an icebreaker and sets the stage for the activities that follow by establishing a safe place of acquainted people.

  The prompts always begin with 'State your name' for each pair. Some example prompts are given below:

- Describe your home + what it looks like.
- Describe what you did last Thursday.
- What's your earliest childhood memory?
- What did you want to be when you grew up?
- Where is the farthest place you're been from home?
- Tell the other person about something new you learned in the last months.
- Who is your role model and why?
- What is your favourite fun-time activity?
- What do you love about your work?
- Describe your best friend and how you met them.
- Describe your favourite family member and why?
- If you would be one animal, what would you choose and why?
- Describe the weather in your hometown during the year.
- What change would you like to see in your hometown in the next 1 and 5 years?

8.4.3.1.2 Narrative-Based Situational Assessment

Participants are divided into mixed-level groups with representatives from village, district, region and national levels. They are arranged to sit in a circle around a table. Participants are asked to recall stories about challenges to climate resilience and adaptation, limitations, as well as things that they are particularly proud of: highlights, strengths, tools and opportunities. The facilitator may set the tone and get things started by telling her/his own story first.

People tell stories naturally and tend to remember stories more easily than they remember facts. Furthermore, stories deliver information with an illustrative context and time stamp, which facilitates interpretation of the response strategies in context. Also, stories beget more stories and once a story circle gets going it provides the basis for very fruitful discussions.

The specific objectives of this activity are for participants to:

- Understand the role that others have in the context of adaptation in Ghana, their perspectives, strengths, limitations, the scope they have to move within and so forth.
- Question assumptions about other people's roles in the issues relating to resilience and adaptation in Ghana.
- Discover one's own blind spots, priorities, frames and context.
- Discover different meanings and frames.
- Develop empathy, respect, open minds, build trust, friendships, values.

Stories deliver information with an illustrative context and a time stamp. Storytelling facilitates capacity development through learning, change and evaluation. Stories provide a 'rich picture' of what is going on in a situation and often carry messages about issues that are directly un-discussable. Stories elucidate social, cultural, physical, economic, political and environmental opportunities and barriers to adaptation.

The primary outcome of this exercise is that participants have a deeper appreciation of the context others are working within. This helps to overcome any culture of blame between decision-making levels ('e.g. farmers are lazy, officials are corrupt'). This activity also generates a collection of narratives that create a 'rich picture' of the status of resilience and adaptive capacity across levels and helps to characterize and identify barriers and opportunities across levels.

8.4.3.1.3 Rich Picture

Participants are divided into groups by level. Each group will produce a rich picture of their own level. They are instructed to consider relevant features of the village/district/region/nation, challenges relevant to climate change, agriculture and food security, tools, and sources of pride.

This exercise produces a detailed visualization of what is going on with respect to climate change, agriculture and food security within each level. Group analyses of each of the diagrams produces deep appreciation of the different worlds that different levels of decision-makers inhabit. This activity allows the group to capture and acknowledge complexity and multiple perspectives within the system and helps to develop empathy for differing people in differing circumstances.

This activity produces rich pictures of what is going on with respect to agriculture and climate change at each level of decision-making within Ghana and provides the visual basis for exploring connections and disconnections between levels in subsequent activities.

8.4.3.1.4 Connecting Levels

Participants are divided into mixed level groups according to theme:

- Agricultural knowledge management.
- Water and land management.
- Basic nutrition and education.
- Markets and finance.

Participants are seated around a round table and in the center of each group is a composite multilevel diagram made up of black and white photocopies of each of the rich pictures constructed during the previous day placed edge to edge sequentially from village to national level. Participants are given three colours of marker:

- Green for links that are working.
- Blue for links that are officially there but are not fully functional.
- Red for links that should be there but are missing.

Participants mark lines on the map representing how knowledge and resources flow across levels within their themes.

The objectives of this activity are:

- To visualize how knowledge and resources flow across levels, thereby identifying
    - Functional links to work with and build from.
    - Non-functional and non-existent links, which represent opportunities for improving the efficiency and effectiveness of adaptation initiatives by ensuring that information, knowledge and resources get to where they are needed across levels.
- To create new insights on what is going on with adaptation in Ghana by sharing cross-level perspectives.
- For participants to experience 'aha!' moments as they see the whole picture coming together.
- To instill hope and optimism about what can be achieved simply by improving alignment and flow.

The expected outcomes of this activity are:

- Cross-level analysis of flows of knowledge and resources relevant for adaptation of agriculture to climate change from national to household level in Ghana.

8.4.3.1.5 Responses Activity

Participants remain in theme-based break-out groups. During this activity, participants brainstorm responses to address any of the non-functional or missing cross-level linkages, building on the functional linkages. Participants are facilitated to think across all levels, considering what conditions would need to be in place at other levels, in order for a response proposed for one link to function effectively. This process of thinking through which actions are needed to support other actions at each level, produces a series of integrated multilevel adaptation response pathways.

The specific objectives of this activity are:

- To generate a range of response options which can improve the alignment and integration of resilience and adaptation initiatives across levels, which have the buy-in of the relevant stakeholders at each of those levels.
- To consider trade-offs and synergies between actions across all levels, thereby producing integrated multilevel adaptation response pathways drawing on the response options identified by all participants.
- Creating a space for positive change.

The primary outcome of this activity is improved cross-level collaboration and implementation of adaptation actions. This activity produces key considerations for National Climate Change Platform implementation. The activity leaves participants with a clear vision that there is an enormous amount that can be done simply by improving alignment and integration of adaptation actions across levels.

8.4.3.1.6 Stress Testing

Participants are divided into 4 multilevel groups and each group assigned one of the CCAFS scenarios for West Africa. The first stage of the activity involves immersion of the group in the allocated scenario through discussion and visualization with the aid of textual narratives and illustrations. Participants are asked to reflect, in the context of the West African situation, what Ghana would look like, what the Upper West would look like, what Tamale and Wa would look like, what Lawra would look like, what villages like Orbili would look like. By discussing the implications of the West African scenarios for Ghana in this way, participants generate multilevel scenarios that are subsequently used to test the multilevel integrated adaptation pathways. Each action in the multilevel adaptation plan is reviewed in light of the scenario and participants consider – would this still work? What could be done instead? In this way, portfolios of options that work in various situations are generated. Also all groups become sensitized to their assumptions about the future and how this affects planning.

Any time we design anything – a policy, an intervention, a technology, it is always designed with a context in mind. How successful it is ultimately depends on whether or not it gets the context it was designed for. With regards to adaptation to climate change, we face a great deal of uncertainty about the future. It is important to sensitize participants to this uncertainty and to examine how the adaptation policies and plans we are making might be sensitive to key uncertainties. Participants broaden their awareness to the context they live within, how plans are sensitive to future uncertainties, how they themselves make many assumptions about how the future will be. They become open to considering new obstacles and opportunities that could present themselves.

This activity has the following expected outcomes:

- Participants develop a greater awareness and openness to future uncertainty, and correspondingly to multiple perspectives and narratives on the future.
    - This develops adaptive capacity within the decision-makers.
    - They feel more secure with uncertainty.
    - They have a greater tolerance for ambiguity.
    - Frustration → Enlightenment.
- The plans developed in the previous activities are stress-tested and a portfolio of additional options is generated.

8.4.3.1.7 Robust Decision Analysis

Participants are returned to their thematic groups. Each thematic group gets back 4 copies of their own plan, which have been tested in each of the 4 scenarios. They are given an opportunity to review how their plan performed in each of the scenarios, to understand the sensitivity of their plans to assumptions about future conditions and to choose options that are robust across scenarios or keep those options that are appropriate to undertake now, with a flag to monitor for changes in future conditions, and a portfolio of alternatives should the need arise.

The specific objective of this exercise is to review the performance of each thematic plan across all four scenarios and to decide on a course of action that is as robust as possible to future uncertainties, along with a portfolio of actions that can be referred to as the context changes. A secondary objective is that decision-makers are made aware that plans are sensitive to future uncertainties and resilience needs to be built in to the planning and implementation process.

The expected outcomes of this activity are:

- Four integrated multilevel resilience and adaptation plans, one within each of the themes, 1) Agricultural knowledge management, 2) Water and land management, 3) Markets, and Finance 4) Basic Education and Nutrition, that have been tested across four diverse future scenarios and are reasonably robust to future uncertainty, and a portfolio of options to refer to in a changing context.
- Decision-makers understand that their plans are sensitive to future uncertainty and are willing to take this into account.

8.4.3.1.8 Cacit Table

CACIT stands for Champion, Approved, Consulted, Informed and Time. A table is made where the first column contains the list of actions within each thematic integrated plan, each subsequent column is allocated to CACIT so that each of these columns must be filled out for each action. Champion refers to who, of the participants, will champion the implementation of this action. The specific objectives of this activity are that the actions identified in the workshop are implemented.

The expected outcomes of this activity are:

- Assigned responsibilities and champions leading to practical outcomes from the workshop.
- This activity avoids implementation gaps
- The actions are incentivized, become real, participants believe in them and their responsibility to take it forward.
- Participants are mobilized for action.
- Creates ownership of tangible steps for action to improve multilevel coordination.

8.4.3.2. Results

8.4.3.2.1 Speed Meeting

Speed meeting was conducted as an ice-breaker during the opening sessions of the workshop. Brief-guided familiarization afforded participants the opportunity to interact and acquaint themselves with one another. Personal life stories, childhood experiences, expectations were shared. It achieved all emotional and rational aims by helping participants to get to know each other quickly, network, learn about each other, feel safe and valued, build empathy and establish friendships. The research team received positive feedback on the activity – it was enjoyed by the participants and all appeared engaged in the process. It set a positive tone for the rest of the workshop.

8.4.3.2.2 Narrative-Based Situational Analysis (Story Circles)

Story circles were conducted in four break-out groups. Translation for non-English participants worked well. All stories have been transcribed in full; summaries are provided here. Participants developed a deeper appreciation of the context others are working within. The activity helped to develop an environment conducive to sharing ideas and perspectives. Avoiding a culture of blame between decision-making levels was a primary objective of the activity. Using blame did not appear to be a problem throughout the subsequent activities. This may be because the participants had a greater appreciation for each other's perspective as a result of storytelling and other activities.

Summaries of the stories from Group 1 are shared by way of example.

GROUP 1

A group member spoke about lateness of rain (It rained in September like it was June): 3000 trees were planted during that time but drought and flood followed which destroyed part of the plantation. It caused very serious management issues. Also 80-90 % of 3 acres of plants submerged due to floods and low ground field.

Olden days soil fertility far better compared to nowadays. A story was told about the beauty of fruit trees that grew well and drew their attention as kids but today that has changed to the extent that one could see the houses behind through the plantation.

Farm sizes are larger these days than before but output is much smaller than before: this is due to climate change according to a farmer.

People attitude promotes climate change (cutting down of trees, bush burning). Heavy downpouring of rain, roads and bicycle were carried away.

Farming on certain plots was becoming very difficult. More storms, typhoons destroyed their mangrove plantations.

2007: Severe change in unexpected climate change with intermittent Flood and drought in 3 Northern regions almost erased everything (experiencing that as a management team member was a sad situation): Help from SADA did not work out as planned.

Identification of disabled people by NGO to enter into dry farming. The projects were going on well but because of insufficient rainfall the project is facing serious problems.

Project: Use of waste as compost to fertilize soils was championed by the women but now men do get involved.

Woman finally assumed the position of leadership amidst difficulties.

Drama play on climate change by Drama group of University of Ghana and mimicking of climate change through toys to communicate to people. Advice on strategies on water conservation.

2 or 3 days of Hamattan, very unusual situation in Ghana and stories about changes in period taken by various weather events around the world.

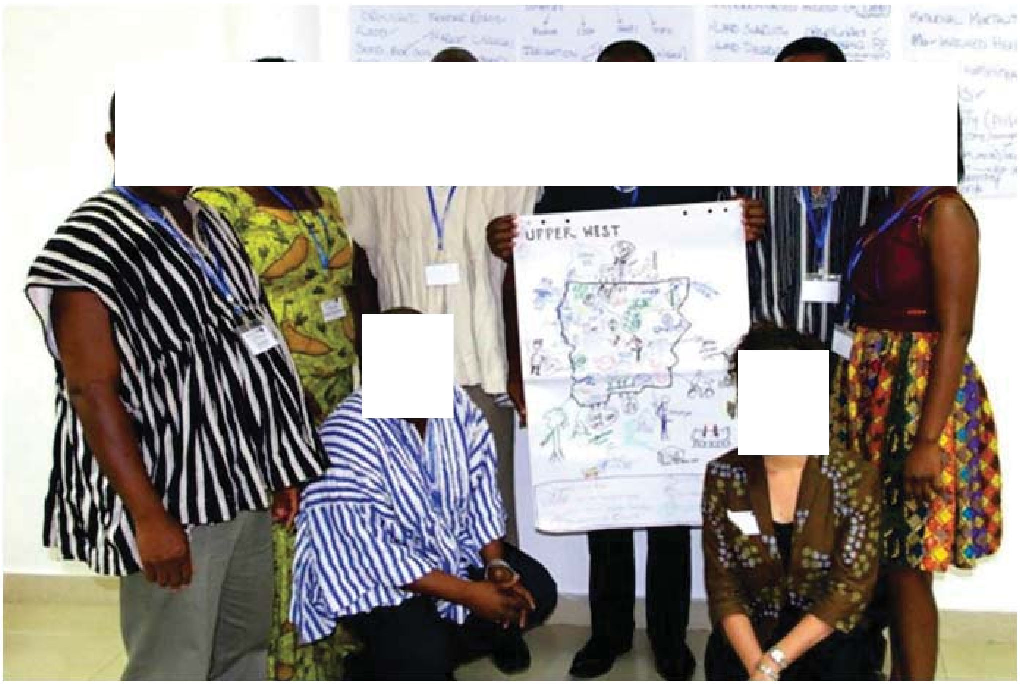
No prominence in global talk on climate change related to livestock. All the focus is on crops

8.4.3.2.3 Rich Pictures

Rich pictures were drawn for each of the four levels – community, district, region and national. These rich pictures were used for connecting the level for each of the four themes.

NATIONAL

REGIONAL



DISTRICT

LOCAL

8.4.3.2.4 Connecting Levels

The participants were divided into breakout groups based on the four themes of:

- Agricultural knowledge management.
- Water and land management.
- Basic nutrition and education.
- Markets and finance

The results for 'Agricultural knowledge management' have been provided by way of example. Full results are available in the SIRA program reports (CCAFS, 2014b).

Table 8.2. Agricultural knowledge management connections

Functional existing links
• Donors to NDPC and the GSGDA II medium term plan
• The NDPC to the MoF for the funding of GSGDA plans
• Donors to CSIR, as most research funding comes through projects
• MoF to CSIR for the payment of wages
• NDPC to the RCC for the preparation of medium term plans, including agric extensions activities
• Donors to MoFA for projects,'We don't have to give the money to MoF if we're funding an agric project. We just go directly to MoFA' (FAO respondent)
• The SARI secretariat in Accra and the head office in Tamale for coordination and administration
• MoFA Accra to the MoFA region on extension policy and practices, and MoFA region to Department of Agric
• GMET with NGOs in Lawra District for collection and utilization of weather information
• NRGP to the community (Black volta landholders) for dry season vegetable gardening
• Radio Upper West to Lawra for forecasting and market information
• NANDOM radio to Lawra community
• Seeds inputs from Lawra agrovets to Orbili
• Orbili weather station data to CSIR (funder of the station) [The problem here is that GMET doesn't receive the data, only the research agency that funded]
• UDS and other University research to community levels

Non-functional existing links

- GMET national to region for data collection and coordination
- SADA to the community,'all the trees have died'
- SARI to the Babili demonstration station
- NRGP to the DA for coordination purposes and plan integration
- GMET regional to national office
- MoFA and CSIR for purchase of foundation seed and improved varieties, and CSIR with Ghana's grain board for the supply of foundation seed
- CSIR- ARI small ruminants program and the Oribili community
- Extension provision from Department of Agric in the community (4/20 extensionists)
- Wa NGOs (very few) and Community for the plugging of the extension gap
- Orbili weather station data to GMET regional office

Non-existent links

- SARI to community for feedback on technology transfer and uptake
- MoF to CSIR for sustained research budget
- GMET Regional office to NGOs at the district level
- The DA and the Babili agricultural demonstration station
- West Link 88.3 radio station and Lawra community (forthcoming)

8.4.3.2.5 Scenarios

The West African scenarios developed by CCAFS regional scenarios program were used as the basis for this exercise. Participants fit each scenario to multiple levels within Ghana by asking questions such as "What would my village look like in this scenario? What would the Upper West look like?" etc. This section provides one of the scenarios and its multilevel adaptation as an illustrative example.

SCENARIO 1: CIVIL SOCIETY TO THE RESCUE?
A scenario where non-state actors are dominant and long-term issues have priority

This is a scenario where active private sector interests aiming for the large-scale commercial development of West Africa vie for influence with vibrant and powerful civil society organizations and NGOs which focus on a more community-oriented, sustainable future. Civil society in West Africa had first realized its strength by successfully leveraging its global partners to help ensure that extra-regional military interventions in Mali would be humanitarian rather than destructive. This powerful civil society and the private sector collaborate as well as compete for influence, often for the better; for instance, contributing to improved livelihoods and knowledge for rural communities. However, tensions arise around issues of land ownership, and here rural people are caught in the middle, though more empowered to play an active role in governance than was possible in previous decades. Gender relations have changed and, amid the other tensions, this transition has been a challenging one. Food security on the whole has improved through a combination of commercial investment in regional food systems, which has raised urban food security, and an increasing professionalization of relatively small-scale farmers. However, uncertainty around the control of land and resources has threatened the stability of incomes for rural communities.

Table 8.3. 'Fitting' Multilevel Scenarios: Civil Society to the Rescue.

National

- Civil society has a very big voice.
- Government is weak and not effective, which impacts all other activities across the country, and brings in new actors. There is a lack of coordination of the government.
- Existing policies need to be revised.
- Rural people have the capacity to produce food.
- Civil society communicates the social benefits for the private sector being involved in services traditionally provided by the public sector; however, the private sector is divided.

Regional

- Localized issues are more adequately addressed than larger-scale issues.
- Determine which initiatives are ineffective.
- Collaboration between NGOs is strong and they have the power to advocate for local communities issues. However they have limited power to enforce and regulate; for example, to regulate against bush burning or to enforce the use of Environmental Impact Assessments.
- Adequate handling of community issues.
- Gender relations are improved, and food security is good. This leads to a reduction of innovation and increase in complacency.

District

- The District Assembly is weak and so there is no coordination resulting in an overlap of efforts. There is a struggle for control of power resulting in conflict.
- There is a prioritization of particular agendas and a misalignment of priorities.
- No enforcement occurs because of the weak local government.

Village

- There are informal arrangements with village members, and corruption rises because of the lack of supervision and enforcement from government. There is lots of competition for resources between villagers.
- Local innovation reduces, as villagers wait for handouts from NGOs.
- The private sector works in some cases and not in others: providing essential services such as water, schools and jobs; while monopolizing due to lack of supervision and enforcement from the public sector.
- NGOs that offer training alone are overrun by NGOs, which provide financial support, as local villagers are attracted to this.

8.4.3.2.6 Response Activity And Stress-Testing

This section combines the results of two activities, the response brainstorm and clustering, pathway development and stress-testing. It provides the stress-tested pathways for each theme. All stress-tested pathways are included since this is a key result. There are four scenarios used for the stress-testing, these are numbered S1, S2, S3 and S4 and correspond to CCAFS four West African scenarios (CCAFS, 2014a).

AGRICULTURAL KNOWLEDGE MANAGEMENT

Goals

To produce an agricultural extension policy and accompanying legislative instrument with the aim of closing the existing extension gap and introducing climate smart agricultural principles into extension curriculum and programming.

Specific Objectives

- Increase the number of female extension agents from the current ratio of 1 female officer for every 10 male extension officers.
- Meet or improve on the current target extension officer/farmer ratio of 1/3000.
- Improve the dissemination of CSA practices.

Table 8.4. Agricultural Knowledge Management Integrated Pathways and Stress-Testing.

Level	Actions	S1	S2	S3	S4	Y/N
National	advocacy regarding the current extension gap.	+	+	?	+	Y
	advocacy of limitations presented by the current hiring freeze and replacement policy.	+	+	+	+	Y
	financing for the development of the 2014 Extension Policy will come from increasing budget allocations to the agricultural sector in order to comply with CAADP and Maputo Declaration targets of 10% of total budget investment in agriculture.	-	?	+	?	Y
	The MoFA directorate of Extension Services and PPMED will be responsible for drafting the policy document.	+	?	+	+	Y
	consult current extension-related components of the FASDEP II and METASIP document, as well as the 2002 Extension Policy.	+	+	+	+	Y
	decision will be made whether to pursue a unified extension system (as is current policy) or allow for more disaggregated training of agents.	-	?	+	+	Y
	A pluralistic model for the policy will be adopted which allows for extension service provision by both government and non-government actors (CSOs, Private Sector), including non-traditional, E-Extension services.	+	?	?	+	Y
Regional	The agric-sector working group will be a key group to be consulted at the national level given it diverse composition.	?	-	+	+	Y
	consulting with Ghana's university system to assess current curriculum for agric extension students.	+	+	+	+	Y
	align existing curriculum with the new Extension Policy to ensure that CSA and other concepts are included in extension staff training.	+	+	+	+	Y
	regional agric M&E officer will also be responsible for aggregating district data regarding existing extension provision data.	+	-	+	+	Y

Level	Actions	S1	S2	S3	S4	Y/N
Regional	the regional will improve collaboration between GMET and E-Extension services like ESOKO to ensure that localized forecasting is available to farmers in extension zones across the country.	?	?	?	+	Y
	RPCU will be key for consultation during the development and implementation of the Extension policy.	-	-	?	+	Y
District	DA will be responsible for hiring and firing of extension staff.	-	-	+	?	Y
	National service in the area of agricultural extension will also be promoted nationally, with national service staffed hired through the DA and Department of Agric.	+	-	blank	?	Y
	Regular RELC (Research/Extension committees) meetings will be budgeted for in the policy, allowing for greater feedback between research agencies (CSIR), extensionists, and yfarmers	-	+	+	?	Y
	yMIS (information systems officer) will be responsible for providing data to the regional M&E officer and for providing district specific policy requirements during the policy development stage.	+	-	+	+	Y
	Mobility of extension agents will serve as a key pillar of the policy, and offer regular budget for fuel and motorcycle transport.	-	-	?	?	Y
	The district director of agriculture will be provided budget within the policy for greater coordination and monitoring of extension agent.	-	?	?	?	Y
	District Agric officers (AEAs) will be trained and equipped with ESOKO mobile phone technology for surveys and the delivery of remote extension consultation.	-	?	?	+	Y
	The DPCU will be key for consultation during the development and implementation of the Extension policy.	-	+	+	+	Y

Level	Actions	S1	S2	S3	S4	Y/N
Village	community will be consulted by the DA during the drafting stage of the Extension Policy so that appropriate M&E indicators can be identified	-	+	+	+	Y
	The community will better organize itself to receive extension service and promote adoption of new CSA technologies	+	+	+	+	Y
	Community based extension workers and training of Trainers (ToT) will allow for more farmer-farmer exchanges	+	+	?	+	Y
	Additional Farmer Field Schools and demonstrations centers will be a centerpiece of the Extension policy.	+	+	+	+	Y
	Motorcade mobile information sharing vehicles will be mobilized in the policy.	-	?	?	+	Y
	ESOKO mobile technologies will be provided to smallholders in pilot districts.	+	+	?	+	Y

WATER AND LAND MANAGEMENT

Goals

Everyone has access to a regular and clean supply of water.

Specific Objectives

- Harmonize efforts of various actors for water provision across all levels.
- Improve maintenance of existing facilities.
- Develop sustainable and affordable water storage and extraction technologies for multiple uses, and reduce siltation, contamination and evaporation.
- Provide sustainable and affordable alternative energy for water extraction.
- Bring in new sources of and more investment in water provision and storage, through PES / CSR from the private sector and renewing government prioritization of water provision at national level.
- Address behavioral dimensions of water usage, related to gender differentiation in collection, usage for washing and sanitation.
- Improve early warning systems to mitigate losses of floods and drought.

Table 8.5. Water and Land Management, Integrated Pathways and Stress-Testing

Level	Actions	S1	S2	S3	S4	Y/N
National	Harmonize efforts of various actors for water provision across all levels, through review of initiatives and policies, and multi-stakeholder platforms. This includes aligning priorities and perspectives of dry season vegetable benefits and trade- offs , and buffer zone laws across ministries.	+	-	+	?	Y
	Design water storage facilities for multiple use including aquaculture to reduce malaria, as well as to reduce siltation of dugouts, contamination and evaporation. This includes increasing education of engineers.	-	-	+	+	Y
	Revive prioritization of water provision in national level. Prioritize government budgets towards previously overlooked regions for irrigation schemes, including Upper West .	-	-	+	?	N
	Improved maintenance of existing irrigation facilities, by government provision of pump repair tools through subsidies.	-	-	?	?	Y
	Government promotes irrigation programs for dry season vegetable farming.	+	-	+	+	Y
	National infrastructure development of sanitation, through the Zoom Lion budget.	-	-	+	+	N
	Research on sub-terrain storage facilities.	-	+	?	+	Y
	Payment for Ecosystem Service (PES) schemes are established through a national policy and the investment of the private sector (mining, oil industry, breweries, banks),	+	?	+	+	Y
	Corporate Social Responsibility schemes are established in the mining and oil industry to provide irrigation facilities. This is partially promoted through advocacy of NGOs of the social benefits to companies.	+	+	+	+	Y
	National media campaigns through the state to improve water management and encourage investment.	+	+	-	+	Y
	Massive government investment in water storage facilities along rivers to capture water during flooding.	-	-	?	+	N

Level	Actions	S1	S2	S3	S4	Y/N
National	National policies for alternative sources of fuel for water pumps, e.g. solar and biogas. This will reduce costs of extraction and deforestation.	+	-	+	?	Y
	Government, private sector and NGOs to purchase water diesel and treadle pumps for dry season vegetable farming.	+	?	+	+	Y
Regional	Ongoing rehabilitation of existing dams in the dry season funded and managed by the RCC and Ghana Irrigation Authority.	-	-	+	-	Y
	Implementation of PES schemes.	-	-	+	+	Y
District	Sensitize community and promote ownership of boreholes and hand-dug wells to encourage local maintanence by MOFA and NGOs.	+	+	?	+	Y
	WASH activities supported by District Assembly and NGOS.	+	?	?	+	Y
	Private sector investments in the districts encouraged through media.	+	+	+	+	Y
	NGOs present community action plans to the District Assembly which implements it to promote water access.	+	?	+	+	Y
	State media (especially media) airs discussion on water usage.	+	+	+	+	Y
	Reforestation supported by Greening Ghana, and the private sector, possibly through REDD+ schemes.	-	+	?	+	Y
	Build more capacity in GMET officers for forecasting.	+	-	?	+	Y
	Improved varieties (water-efficient and short-maturing) are developed by CSIR and technology is disseminated by MOFA.	+	-	+	+	Y
Village	Land tenure is secured to set the context for PES schemes.	-	?	?	?	
	Key parties in villages are assigned responsibility for maintenance (for hand-dug wells, dugouts and boreholes).	+	?	+	+	Y
	Educate men and women the community roles about sharing responsibility for water collection.	+	+	+	+	Y

Level	Actions	S1	S2	S3	S4	Y/N
Village	WASH activities are implemented, including improved sanitation to reduce water course contamination and education about washing activities away from water sources.	+	+	+	+	Y
	Capacity building in the sustainable management and maintenance of dugouts. This includes breaking down community misperceptions through education, training and the demonstration of new technologies (storage and new varieties).	?	+	+	+	Y
	NGOs advocate and train on avoiding farming on the banks of waterways and dugouts to reduce topsoil runoff, siltation and infill of rivers, which flood in the rainy season.	+	+	+	+	Y
	Aquaculture schemes along riverbanks by the private sector.	+	+	+	+	Y
	Encourage rainwater harvesting.	+	+	+	+	Y
	Reforestation along river banks to reduce topsoil runoff.	?	+	?	+	Y
	Soil moisture management.	+	+	+	+	Y
	Reduce land clearance and deforestation.	-	?	?	+	Y
	MOFA disseminates improved varieties of seeds.	+	-	+	+	Y
	Radio forecasts are broadcasted in local languages.	?	+	+	+	Y
	NGOS develop community action plans to use water pumps, treadle pumps, dugouts.	+	+	+	+	Y

MARKETS AND FINANCE - FERTILIZER MANAGEMENT SYSTEM

Goals

Efficient and Sustainable Fertilizer Management System

Specific Objectives

- Availability of knowledge for sustainable application of fertilizer including timing of reapplication. Matching use with crops.
- Availability of fertilizers at farm level when needed (at subsidized price).

- Livelihood options of farmers especially women to generate funding/savings for fertilizer purchase.
- Fair allocation of fertilizer quota at regional and district level, with accountability of district directors for the management system
- Timely issuance of fertilizer subsidy policy, quota allocation and cash transfers to ensure timely import/manufacture of national fertilizer stock to match national needs.

Table 8.6. Markets and Finance Integrated Pathways and Stress Testing.

Level	Actions	S1	S2	S3	S4	Y/N
National	Delay in cash transfer of subsidy by government to importers/manufactures, leading to delay in fertilizer availability. The reason is that, while expenditure is clear, the revenue is an estimate that often falls short. Part is the dependence on foreign grants to plug budget deficit (example Euro 40m held by EU) • (Advocacy) Set-up of MOFA. MoF, Donor and Fertilizer supplier. Committee to plan and coordinate quantity, timing, funding of fertilizer import.	-	-	+	?	Y
District / Region	Accountability of District and Regional Directors/ Procurement. • Monitoring evaluation and tracking system at the region and district level to monitor the quantity of fertilizer entering the district and region – "ESOKO" system.	+	-	+	+	Y
	• Power to take action/report the officials found in violation of the policy.	+	?	+	?	Y
Village	Illegal sale of subsidized fertilizer to Burkina Faso and other districts at higher price: • Inclusion of farmer representative in fertilizer allocation committee at district level in the allocation of quotas and quantity received for timely dissemination of fertilizer availability.	+	+	+	+	Y
	• Monitoring system as discussed in District.	+	-	+	+	Y

Level	Actions	S1	S2	S3	S4	Y/N
Village	Farmers selling fertilizer subsidy passbook to Dealers because of lack of funds. • Generating alternate sustainable livelihood options for generating funds for fertilizer purchase.	+	+	?	+	Y
	• Village saving schemes to pool money for fertilizer purchase.	?	+	+	+	Y
	• Micro Credit from banks – facilitated by NGOs such as IDE.	-	+	-	+	Y
	• Assistance from Peasant Farmers Association.	+	+	?	+	Y
	Low Extension to Farmer Ratio (Challenge for knowledge dissemination) – Not focusing on national policy for extension services but at community level to bridge the extension gap. • Community based training of farmers (show case) –'Talking Book' tools.	+	+	+	+	Y
	• Motivating volunteering by offering 'Best Volunteer Award' through dedicated district budgets.	?	-	+	+	Y
	• Linking national service –Training on agric service and deputing in districts/villages.	+	-	+	+	Y
	• Training is usually done by projects (NGOs) during projects but not sustainable. Need to institutionalize it through using the formal concept of 'Contact Farmer'.	+	?	+	+	Y

BASIC EDUCATION AND NUTRITION

Goals

Everyone (particularly children from 0-4) has access to nutritious food at all times.

Specific Objectives

- Rural communities are aware and educated about (child) nutrition.
- Short-term child malnutrition problems are tackled through reinforcing and improving on child feed programs combined with weighing.
- Agricultural and health policies are integrated to provide nutrition and soil fertilization through crop diversification.

Table 8.7. Basic Health and Nutrition Integrated Pathways and Stress-Testing

Level	Actions	S1	S2	S3	S4	Y/N
National	The Ghana Health Service (GHS), the Ministry of Food and Agriculture (MoFA) and a university set up a joint platform with farmers associations, CARE and NGO's from the nutrition network (linked to district level).	-	-	?	+	Y
	Based on the national platform, GHS + MoFA shift funding to connecting health and agricultural policies on, 1) education and awareness raising on nutrition, 2) feeding programs connected to health checks for young children and, 3) diversification of crops to improve soil fertility as well as nutrition.	-	-	+	+	Y
	Women's voices need to be heard in the platform to help prioritize on child nutrition.	+	?	+	+	Y
	Farmers associations, nutrition networks + CARE + media advocate change (linked to district level).	+	+	?	+	Y
Regional	Regional governments are strengthened in their capacity for supervision of out-scaling as well as monitoring and evaluation.	?	-	+	+	Y
District	A proposal for a district-level case study focusing on three elements (awareness, child food provision combined with healthcare and diversification of crops for nutritional diversity and soil fertilization) is initiated by the farmers association + CARE + nutrition network NGOs.	+	+	+	+	Y
	The District Assembly helps fund and set up the district-level case study	-	-	+	+	Y
	Community Health Officers are trained and deployed to all communities to organize volunteers.	?	?	+	+	Y
	Bi-laws are established to stop bush burning to save wild, nutrient-rich foods (berries, dawadawa).	?	-	+	+	Y
	Nutrition officers provide education on child nutrition and monitor results.	?	+	+	+	Y

Level	Actions	S1	S2	S3	S4	Y/N
District	Early childhood education on nutrition is provided through the District Assembly	?	?	+	+	Y
Village	A CHPS compound is established in the community.	?	?	?	+	Y
	Kobina (traditional Lawra festival) is used as an opportunity to raise awareness.	+	+	+	+	Y
	Soybean and maize intercropping, legumes and fruits help contribute to nutrition and soil fertility.	-	+	+	+	Y
	Awareness is built around the eating of fruits and vegetables.	?	+	+	+	Y
	Community buy-in with awareness/ feeding/crop diversification program is established.	-	+	+	+	Y

8.4.3.2.7 Robust Decision Analysis

Following the stress-testing of the integrated response pathways, the four thematic area plans were revisited. A complete multilevel narrative was produced by the groups. The Agricultural Knowledge Management group results have been included as an illustrative example. Notes on specific amendments to the plans following the stress-testing are also included here when available.

AGRICULTURAL KNOWLEDGE MANAGEMENT

In the discussion following the scenarios, the areas of 'extension mobility'and 'greater director coordination of extension agents'were flagged as highly contested across all of the scenarios. These elements were not removed from the action list, however. It was thought that they could be accounted for by adding an element of district and regional capacity building and on-the-job training for incoming AEAs into the plan. The composition of the policy development team and implementation team needed to be more diverse and rely less on government than initially envisioned. A multi-stakeholder steering platform should be developed and the policy should adopt a sector-wide approach, which allows for the centralization of funding sources from donors and government alike.

Table 8.8. Multilevel Narrative for Agricultural Knowledge Management.

National Level
Action at the national level first includes advocacy regarding the current extension gap and illuminating the investment losses from subsidizing the training of agric offers in Ghanaian universities and then failing to hire those same individuals into the extension workforce. The limitations presented by the current hiring freeze and replacement policy (as per donor human-resource spending ceilings) will also be highlighted in this advocacy component. It is envisioned that the financing for the development of the 2014 Extension Policy will come from increasing budget allocations to the agricultural sector in order to comply with CAADP and Maputo Declaration targets of 10% of total budget investment in agriculture. It is likely that this will require empirical evidence of the current status of agricultural budgeting. The MoFA directorate of Extension Services and PPMED will be responsible for drafting the policy document and program of action, as well as serving as the policy's principal advocates and champions. They must consult current extension-related components of the FASDEP II and METASIP document, as well as the 2002 Extension Policy. SRID (Statistics) will be consulted for the current state of extension service provision. A decision will be made whether to pursue a unified extension system (as is current policy) or allow for more disaggregated training of agents (i.e. veterinary track, crops, livestock). A pluralistic model for the policy will be adopted which allows for extension service provision by both government and non-government actors (CSOs, Private Sector), including non-traditional, E-Extension services. Commercial extension services and out-grower/nucleus farmer schemes will be considered. The agric-sector working group will be a key group to be consulted at the national level given it diverse composition.
Regional Level
The regional levels' role in the 2014 Extension policy is principally one of consulting with Ghana's university system to assess current curriculum for agric extension students, ensure a sustainable extension workforce in years to come, and to align existing curriculum with the new Extension Policy to ensure that CSA and other concepts are included in extension staff training. The regional agric M&E officer will also be responsible for aggregating district data regarding existing extension provision data (coordinating with SRID at the national level). Finally, the region will improve collaboration between GMET and E-Extension services, like ESOKO, to ensure that localized forecasting is available to farmers in extension zones across the country. The RPCU will be key for consultation during the development and implementation of the Extension Policy.

District Level
The district's role in the new extension policy will be heightened by fiscal and administrative decentralization. The DA will be responsible for hiring and firing of extension staff, reducing the trend of Accra choosing the location of 'replacement' staff. National service in the area of agricultural extension will also be promoted nationally, with national service staffed hired through the DA and Department of Agric. Regular RELC (Research/Extension committees) meetings will be budgeted for in the policy, allowing for greater feedback between research agencies (CSIR), extension officers, and farmers. The MIS (information systems officer) will be responsible for providing data to the regional M&E officer and for providing district specific policy requirements during the policy development stage. This includes differentiating extension requirements for different farmer classifications (e.g. subsistence, commercial, export-oriented). The district director of agriculture will be provided budget within the policy for greater coordination and monitoring of extension agents. That is, information regarding the geographic coverage and projects managed by a given agent, so that M&E and demonstrations can be better coordinated and duplications avoided. Mobility of extension agents will serve as a key pillar of the policy, and offer regular budget for fuel and motorcycle transport. District Agric Officers (AEAs) will be trained and equipped with ESOKO mobile phone technology for surveys and the delivery of remote extension consultation. The DPCU will be key for consultation during the development and implementation of the Extension policy.
Community
The community is to be consulted by the District Assembly during the drafting of the Extension Policy so that appropriate M&E indicators can be identified and included in the Policy Log Frame to ensure accountability. Indicators like 'number of visits', which are not reflective of actual outcomes, will be replaced by more appropriate results-oriented indicators. The community will better organize itself to receive extension service and promote adoption of new CSA technologies. Community-based extension workers and Training of Trainers (ToT) will allow for more farmer-farmer exchanges. Additional Farmer Field Schools and demonstrations centers will be a centerpiece of the Extension policy. Motorcade mobile information-sharing vehicles will be mobilized in the policy. ESOKO mobile phone technology will be provided to farmers in pilot districts, along with necessary top-up credit to ensure the sustained use of the e-extension resource.

8.4.3.2.8 Workshop Evaluation

93% of respondents said the workshop met their expectations. The main benefits highlighted related to:

- Learning the facilitation processes and the methods used.
- Networking.
- Communicating to higher levels of decision-makers.
- Scenario planning produced strategic capacity development.

- The main recommendations for future multilevel workshops are as follows:
- More time allocated to each of the activities and increase the number of days.
- Explain briefly the facilitation techniques.
- Future versions should be organized at the regional level in Tamale or Wa so that participants from the southern sector can feel the climate of the northern sector. Include field trip to Lawra to have a feel of the local conditions.
- At the beginning of the workshop, have a presentation on climate change in video format.
- Use sculpting material in addition to drawing for rich picturing.
- Presentation of the findings of the research from the CCAFS SIRA team in Lawra from 2013 and 2014.

8.5. Broader Measures: What Could Be Done About It More Generally

The measures taken within the SIRA program do not address the issues with interdisciplinary collaborative research outside the program. This section provides suggestions about measures that could be taken more broadly in order to create the conditions that will make resilience research feasible.

Incentivize Collaboration

There is a conflict of interest between the individualistic performance measures of academia and the requirements of knowledge sharing, joint analyses and integration necessary for genuine interdisciplinary research in teams. This conflict of interest could be managed at the institutional level by adding formal performance measures that incentivize sharing and collaboration directly.

Novelty versus Societal Relevance

The issue of conflicts of interest regarding academic novelty versus societal relevance and usefulness could be addressed by reducing the degree to which academic performance is judged based on citations and impact factors. Publications in journals require scientific novelty and, as long as bibliometric measures of academic performance dominate, this conflict of interest will be an issue. The 'Science in Transition' movement in Europe is already working in this direction, recognizing that 'Science has become a self-referential system where quality is measured mostly in bibliometric parameters and where societal relevance is undervalued' (Huub Dijstelbloem et al., 2014). They suggest that groups of scientists and societal stakeholders be involved in critical processes to establish quality on the basis of substance.

Integrating Knowledge across Disciplines

Providing researchers involved in interdisciplinary teams with basic training in the history and philosophy of science, so that they will be able to understand that different disciplines have different epistemological and ontological foundations etc., so that they would be able to situate their own position within a broader framework. Training in the practice of 'critical appreciation of alien paradigms', described in Chapter 5, would allow otherwise threatening situations to become fantastic opportunities for learning.

Interpersonal and Personal Issues

Interdisciplinary research in teams requires a very specific set of skills. Researchers need to be able to:

- Listen very actively.
- Be prepared to change fundamental views in order to cope with new information.
- Be able to handle criticism without defensiveness or righteous indignation.
- Understand that ignorance is inevitable and not just a lack of professional competence that needs to be covered up.
- Be able to be wrong.
- Be able to handle their stress while working in the team without using people around them as an emotional dustbin.

Essentially, interdisciplinary research in teams requires a great deal of emotional intelligence. These are skills that can be developed through basic training programs. Integrating reflective practice of different kinds into research practice can also help in managing these issues. Combined with interdisciplinary training, emotional intelligence training can also help researchers to understand the value of working together with others, of sharing knowledge and sharing credit for outputs. The Association for Contemplative Mind in Higher Education is already working along similar lines (ACMHE, 2014).

8.6. Conclusion

Researching resilience requires working in collaborative interdisciplinary teams. It requires multiple perspectives, an in-depth knowledge of the many relevant topics in any given context that can only be provided by multiple people. Working with multiple stakeholders is essential and multi-stakeholder processes require a team of researchers to facilitate and interpret.

Throughout the SIRA program, there were many instances of successful interdisciplinary collaboration, including the diagnostic and planning workshop described in Chapter 5, the scenario-exchange program described in Chapter 6, and the Ghana workshop described in Section 8.4.2. In the instances where there was collaboration, incredible achievements were obtained by everyone and by the program as a whole.

Putting researchers from multiple disciplines together in a project is not enough to guarantee genuinely integrated interdisciplinary research in the team. Long periods of time in the field together conducting shared action research activities, followed by structured dialogues is also not enough to guarantee genuinely integrated interdisciplinary research in the team. While these two conditions are helpful, integrated applied interdisciplinary research remains challenging for the following reasons:

- External pressures and incentives:
    - Individualistic academic performance measures, and a lack of performance measures incentivizing knowledge sharing and collaborative analyses.
    - Conflict of interest between novelty and societal relevance in academic performance measures and incentive structures.
- Theoretical and practical issues integrating knowledge across disciplines:
    - Different disciplines have different ontological (the way things are) and epistemological (what we can know about the way things are) foundations; different ways of dealing with truth, complexity, diversity, pluralism; different ways of framing issues, different methods for generating and handling knowledge; different methods for arriving at decisions; different approaches to quality control and rigour; different standards about what constitutes data and evidence; suggest different types of solutions.
    - Some disciplines perceived to have more legitimacy than others.
- Interpersonal dynamics which have a major effect on the research process and its outcomes:
    - Perceptions of particular biases held by one group member in the eyes of other group members which make them more or less receptive to the perspectives of that group member.
    - Perceptions of agendas relating to power, control or self-promotion.
    - Interdisciplinary research requires a great deal of emotional intelligence.

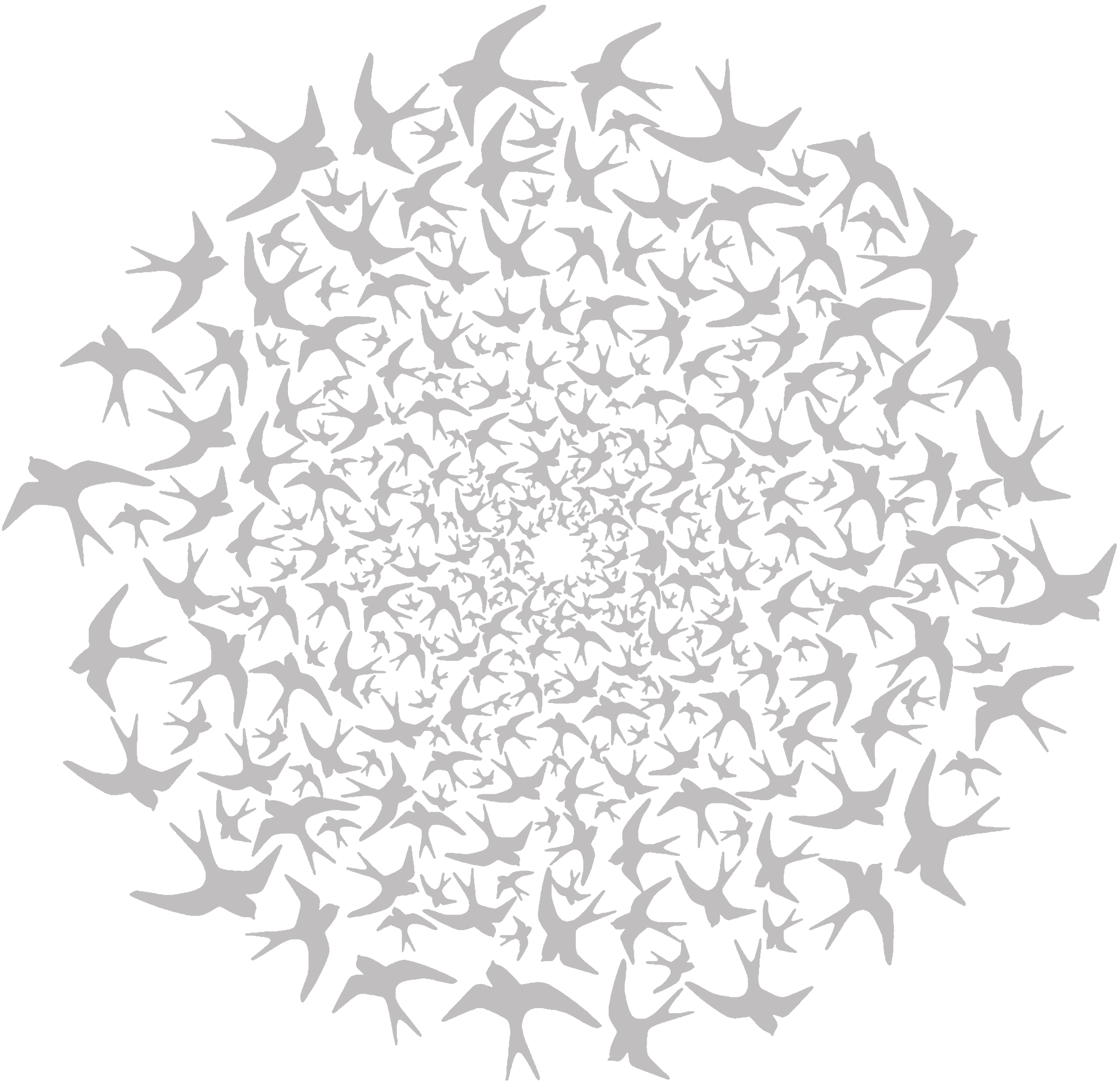
Narrow self-interest works against collaboration: each lens has an individual PhD to write and must answer to the demands of their candidature. From this perspective, collaboration came to be seen as an additional burden that interferes with their individual research schedule.

From another perspective, the collaboration within the SIRA project could be seen as an opportunity to achieve novel contributions within each PhD that could not have been otherwise reached. SIRA provides the participants with a support structure that is rare within PhD programs, including funding for extended field research and involvement in unique research contexts. Their participation in the project will set them apart from other PhD graduates, particularly with respect to their capacity to perform action research to improve real world situations that demand multiple perspectives to be accounted for and multiple lenses to make sense of. Beyond self-interest, it is clear that the team is motivated towards making a difference for smallholder farmers' capacity to help themselves to secure and improve their families' livelihoods. Each researcher has a role as an Oxford student, a role as a member of CCAFS, and a role as a human being. As human beings, contributing to a worthy greater cause gives meaning to our lives and helps us to connect with other human beings. From this perspective, integration is not a separate activity to be performed on top of individual research. It is woven into the fabric of the experience of the SIRA project.

In order to address these issues within the SIRA team, we conducted two internal workshops, one focused directly on research integration and the other focused on Ghana, and facilitated a process in Ghana to co-develop integrated multilevel pathways to increase resilience and adaptive capacity. All of these activities were successful and provided unique insights. However, there is still a need for actions to be taken to enable resilience research more broadly:

- Motivate collaboration with the right incentives from the start of the program:
    - Incentivize collaboration with performance measures that reward knowledge sharing and collaborative analyses and output development.
    - Motivate collaboration with stakeholders and the development of appropriate approaches and solutions by valuing societal relevance of research and reducing the focus on academic novelty.
- Provide training in:
    - Reflective practice and emotional intelligence
    - Provide interdisciplinary practitioners with enough background in history and philosophy of science to navigate knowledge generation and negotiation in an interdisciplinary team.
        - Truth, Pluralism, Partial Views
        - 'Critical appreciation of alien paradigms'.
        - Ability to critique the dominant paradigm in terms of pluralism, epistemology and ontology, in any so-called 'interdisciplinary' research program.
    - Incorporate this into courses for undergraduates, post graduates and professionals!
- Increase time available in research programs for:
    - Building trust, understanding and relationships.
    - Sharing knowledge and understanding where the other person is coming from.
    - Reflective practices.

There are fledgling movements in science higher education that recognize these needs and have begun working towards these ends, such as the Association for Contemplative Mind in Higher Education and the Science in Transition movement. It is the hope of the author that space is created for interdisciplinary research to take place with the right incentives and supported by training that is not currently standard in academia, but on which successful collaboration depends.



9.

Conclusions

9. Conclusions

Resilience has become a key theme of research, policy and practice across disciplines and sectors around the world (Folke 2006, Leach 2008, Young et al. 2006, Bhamra, Dani, and Burnard 2011, Martin-Breen and Anderies 2011, Walker et al. 2004, Walker et al. 2006, Starr, Newfrock, and Delurey 2003, Birchall and Ketilson 2009, Council of Australian Governments 2009, Government of Nepal 2010, Thompson 2009, European Commission 2012, World Bank 2011, United Nations Office for Disaster Risk Reduction 2007). However, there is lack of agreement about what resilience means conceptually, mathematically and in practice.

The inherent conceptual and operational pluralism extant in the field is problematic for those involved in resilience management, planning and decision-making; particularly in the multi-actor and multi-scale processes that are called for by the very concept of resilience. Acknowledging interconnectedness of social, economic, political and environmental systems across scales and levels, taking into account cross-scale and cross-level interactions, and striving towards holism are fundamental aspects of the resilience approach. Thus, frameworks that can handle this diversity across disciplines, sectors and social worlds scales are needed. This thesis has presented systemic frameworks for understanding, measuring and managing resilience that are designed to work with and capitalize on this inherent pluralism and accordingly build capacity to cope with uncertainty and change.

The frameworks presented have been operationalized and tested over the past three years in Climate Change Agriculture and Food Security (CCAFS) on going Systemic Integrated Resilience and Adaptation program and linked Regional Scenarios Program. The Systemic Integrated Adaptation program is fundamentally concerned with small-holder farmers and the integrated social, economic, political and environmental systems in which they are embedded. It co-identifies and supports appropriate adaptation actions at multiple levels from national to individual, according to the principle of subsidiarity and adopts a critical dialogical approach to system definition and boundary judgments. The Regional Scenarios program explores diverse plausible futures for CCAFS regions through a process designed to expand decision-makers capacity to cope with uncertainty and complexity and to build strategic capacity. Both programs operate in five regions: East Africa, West Africa, South-Asia, South-East Asia and Latin America. This thesis has focused on case studies in Nepal and Ghana, and presented a global food systems model. Relevant resilience planning frameworks and the approaches taken to cross-level, cross-scale and cross-research program integration have been described.

Resilience has been described as a boundary object since it is a flexible concept, interpreted differently in different disciplines, sectors and social worlds, but it has enough common threads to be recognizable (Brand and Jax 2007). The central common thread is that resilience relates to the response of a system to disturbance or change, whether that disturbance is sudden and shocking or slow and gradual. When a system is subjected to disturbance, there are only three possible outcomes: it stays in the same state, it does not initially stay in the same state but returns somehow, or, it does not stay in the same state and does not return, but goes somewhere else. Each definition in the resilience literature describes one or more of the following three types of behaviour:

1. Robustness: absorbing the disturbance and maintaining the values of certain variables/ properties; ability to resist change.
2. Stability/Recovery: recovering from the disturbance and returning to the original values of certain variables/properties.
3. Adapting and benefiting: adapting as a result of the disturbance and moving to a new state that is at least as desirable as the original, potentially more so.

If a system is able to withstand disturbance, it will be called resilient; if a system is able to recover from disturbance it will be called resilient; if a system is able to improve following disturbance it will be called resilient. The only response to disturbance that is not considered resilient is when the system changes to an alternate state that is less desirable than where it was prior to the disturbance.

All three types of behavior are still currently in use in isolation and in combination under the name of resilience. Resilience practitioners each have their reasons, which make sense in their context of application, for adopting a particular understanding of resilience in terms of one or more of these types of behaviour. In order to communicate and collaborate in interdisciplinary, inter-sectoral and inter-agency settings, it is useful to adopt a definition of resilience that incorporates all three types of behaviour as ways that a system can handle change without undesirable outcomes. All three types of behaviour are strategies for dealing with disturbance and avoiding transition to an undesirable state. Including all three types of response is consistent with Holling's original seminal definition of resilience as the capacity of a system to absorb and utilize and possibly even benefit from disturbance (Holling 1973). Trade-offs exist between the three types of response to change (absorbing/ resisting, stability/recovery, adapting/benefiting) described above, both within and across system scales, and across types and scales of disturbance.

The notion of desirability, or benefiting from change, is repeated throughout conceptual, empirical and mathematical resilience literature. The value judgement of what is desirable and what constitutes improvement or detriment is observer-dependent. Changes that benefit one stakeholder may be detrimental to another. Who gets to define what is desirable and what is beneficial? A change that is desirable to one stakeholder may be detrimental to another. This raises some very interesting challenges to operationalizing resilience in practice and directly points to a number of ethical considerations, particularly in the development and resource management sectors, where what constitutes development or improvement, for whom and by whom, has predominantly been decided by the haves and not the have-nots.

Specifying which of the three types of behaviour described above we are concerned with is still not adequate to allow resilience to be characterized, measured or managed in practice. Where system boundaries are drawn, what types of disturbance are being considered, what constitutes desirable change to whom, and what is the time frame for assessment of the desirability of the system response, will determine what is interpreted as resilience or adaptation versus vulnerability or collapse. In short, we need to specify resilience 'of what, to what, from whose perspective and over what time frame'.

Chapter 4 described how the ancient Mayan Civilization can be interpreted as an archetypal example of collapse (Diamond 2005), or a stunning example of adaptation and resilience (McAnany and Yoffee 2009), depending on definitions of what is adapting, what makes that system what it is (how civilization is defined), and what constitutes desirable change. Chapter 4 also provided examples of how systems can be very resilient to one type of disturbance while being utterly vulnerable to another type, such as the 'robust yet fragile nature of the internet' (Doyle et al. 2005), the resilience of Mumbai slum dwellers to year on year flooding and their simultaneous vulnerability to viral epidemics (Varghese 2010), the engineered robustness of agriculture in Goulburn Broken Catchment to water scarcity leading to increased vulnerability to flooding and water-logging (Eakin et al. 2009). The case of Goulburn Broken Catchment also highlights the importance of time frame, since it determines the relevant disturbances, and also determines whether or not the features of interest have recovered in an acceptable fashion.

In summary, resilience is a property of a system that describes the nature of the response of the system to a particular disturbance, of a particular magnitude, from the perspective of a particular observer over a specified time frame. Thus, any method we use to characterize resilience qualitatively or quantitatively relies on a clear specification of the boundaries of the system under consideration (of what), the type and magnitudes of disturbance to be considered (to what), what constitutes desirable change to whom (which type of behaviour is relevant to which features of the system, what must be preserved, what must recover, what can change in a manner deemed beneficial – from whose perspective) and what is the time frame for analysis (over what time frame). These key issues represent a framing cycle, since the system boundaries indicate who is a legitimate stakeholder – and those stakeholders may reframe the relevant system of interest – and the time frame indicates the disturbances that are relevant; consideration of these factors may affect the system boundary judgements and so on.

Resilience grew out of a desire to be holistic, to avoid the oversimplifications and narrow reductionist approaches that led to poor stewardship of human and natural systems and collapse in the past (Walker et al. 2004, Hughes et al. 2007). According to a widely held understanding of the resilience idea, resilience thinking means an effort to 'look at the whole' of an issue (Walker and Salt 2006, Folke et al. 2010). That is, to include the entire relevant problem environment in one's definition of a modelling, design or governance problem. This claim to holism is something that has been taken for granted in much of the resilience literature. It has been a very fashionable idea and it represents a self-justifying ideology: that resilience science is comprehensive rather than reductionist.

Another important part of taking a resilience approach is acknowledging the fundamental interdependence and interrelatedness of physical, social, economic, political and ecological dimensions of life across all scales (Walker and Salt 2006, Gunderson and Holling 2002). Comprehensiveness is challenged because comprehensive thinking on social and ecological issues 'can find no natural boundaries' (Ulrich 1993). Because of the fundamental interdependence and interconnectedness of all things, comprehensiveness would imply expanding our system boundaries to include 'the World and God and everything', which is simply not possible because there are limits to our understanding. We cannot have a God's eye view of everything. Thus, normative system boundary judgements are inevitable (Ulrich 1983, Midgley 2000).

This holistic notion of resilience is fine in itself, but it is practically useless. Holism is a worthy goal, but it is unachievable in practice due to the fundamental interdependence and interrelatedness of all things and the inevitable limitations of human understanding. To some degree, this problem has plagued resilience in practice, with some perception that the best resilience thinkers are those with the biggest models. According to Ulrich, 'the quest for comprehensiveness, although it represents an epistemologically necessary idea, is not realizable' (Ulrich 1993).

Since system boundary judgements are both inevitable and inevitably normative (Ulrich 1983, 1993, Midgley 2000, Midgley 2003) and resilience can only be judged relative to system boundaries (of what, to what and so forth), resilience is also inevitably normative. The real challenge posed by the resilience idea is not that in order to be rational we need to be omniscient but rather, that we must learn to deal critically with the fact that we never are. Also, since we only ever have a partial view, there will always be unanticipated side effects of any intervention, which means resilience can ultimately only be assessed in hindsight (at which time notions of desirability might have changed).

These difficulties are not showstoppers; they do not need to paralyze us but we simply cannot rest on unjustifiable claims of objectivity and must turn to post-normal science and critical systems thinking for rigorous approaches for handling the normative content of our investigations, analyses, conclusions and recommendations. In the words of Kant 'We cannot, by complaining about the narrow limits of our reason, escape the responsibility of at least a critical solution to questions of practical reason' (Kant 1787).

Resilience requires a critical and reflective approach to meaningfully operationalize. In Chapter 5 it was discussed that, if we can choose between different system boundaries, we can also choose between different theories and methods. Accordingly, critically and reflectively investigating resilience involves employing theoretical and methodological pluralism, as well as system boundary critique. It is only by involving as many diverse subject matter experts and stakeholders as possible in this process that unanticipated negative side effects of any intervention can be minimized. Furthermore, since we can only ever have a partial view of the relevant problem context, there will always be some unanticipated consequences of any resilience intervention. Accordingly, our approaches must be reflectively assessed and improved through an iterative process of feedback loops. This understanding forms the basis of the reflective, iterative, participatory approach to operationalizing resilience advocated in this thesis.

Any characterization or measurement of resilience relies on many normative decisions: definition of system boundaries, types of relevant disturbance, timescale of analyses, and desirable versus undesirable features. Where system boundaries are drawn, what is included in the analysis, which features of the system are allowed to change and which must be preserved, and what sorts of change constitute improvement within those boundaries, completely determines what is interpreted as resilience, adaptability, vulnerability or collapse and so forth. Quantifying resilience is not made objective through the use of rigorous mathematical modelling techniques and transparent, replicable measures. It still entirely depends on the specification of resilience 'of what, to what, from whose perspective and over what time frame', all of which are normative judgements that will be made differently by different inquirers, depending on their purpose, values, world views and so on.

Chapter 7 applied mathematical measures consistent with the conceptual framework presented in Chapter 4 to food system resilience. In order to apply these measures, the operational framework presented in Chapter 5 had to be applied. In order to quantify resilience, the following is needed:

- A model of the system of interest which quantifies the response of the system to disturbance or change, which itself requires the following:
  - Which variables to include in the model and which, out of the universe of possibilities, can be left out – this includes the resilience 'of what' question.
  - What type of change we want to model; this includes knowing what types of disturbance, since the disturbances need to be capturable by the model. Thus, this includes the 'to what' question.
  - Knowledge of how the elements of the system relate to each other and interact. This can be expressed in equations, or the relationships can be expressed in terms of rules of interaction for an agent-based simulation. In the case of wicked problems, different stakeholders will have different knowledge about this, and will structure the world differently.
- A definition of what constitutes desirable or undesirable change. Two different preference functions were used in Chapter 7 to demonstrate the fundamental dependence of resilience measures on notions of desirability, even in a quantitative sense.
- Specification of the time frame for analysis.

Though rigorous and mathematical, these items are not objective and value-free, and it is important to involve as many diverse stakeholders and experts as possible in the process of model development. Many participatory modelling techniques exist – this thesis applies fuzzy cognitive maps and system dynamics models, as they are capable of handling feedbacks, whereas some other approaches such as Bayesian Belief Networks cannot. Whatever type of mathematical model is used, its development should be embedded in an appropriate participatory process for framing resilience and making explicit the world views that underpin the modelling assumptions to all of those who will use the model for decision-aiding.

Chapter 7 also generated many insights about participatory modelling using Fuzzy Cognitive Maps and for using FCM to quantify resilience of social-ecological systems. FCM and system dynamics models are somewhat confabulated in the social-ecological and resilience literature (Kok 2009). However, FCM and system dynamics models are different models that require different data in their formulation and answer different questions. FCMs model uncertain and ambiguous causes and system dynamics models model unambiguous effects. For FCMs and system dynamics models, the placing of weights on the links of the graph is very different. FCM asks 'how certain are you that this causal link exists' whereas system dynamics models ask 'what is the magnitude of effect of one variable on the other'.

The choice of FCM versus system dynamics model changes:

- How the activity is framed and explained to participants in terms of what is being done, what the purpose is and what outcomes and outputs should ideally be.
- It changes what questions you should ask participants and what data to collect. For FCM links, 'How certain are you about the existence of this causal relationship?' versus 'How much does this variable affect the other?' are very different questions, which are likely to produce different weighted graphs.
- It changes the type of information you can get from the model. FCM models can tell us what our knowledge system indicates will be caused from a particular intervention or any given set of initial conditions, together with the uncertainty associated with this inference. The system dynamics version can tell us the magnitude and direction of change of the values of the variables in the model, for a given initial perturbation.
- It changes the mathematical rules of the calculations that need to be applied.

All of these items have a significant impact on the decision-aiding process and on the conclusions and recommendations drawn for action. A coherent mathematical model with consistent conceptual interpretation and practical implementation is important for the quality of the results and the meaning derived from the exercise.

FCMs continue to be used and continue to have a lot to offer; so do system dynamics models, though they serve different purposes. Work has been done to put cause and effect together. Theoretically, it should be possible to ask people where they think causal links exist, how certain they are that the causal link is there, and also what the magnitude of effect is. In order to 'fuzzify' the magnitude of effect, participants could be asked for a range of values instead of just one. FCMs, system dynamics and other forms of participatory modelling contain many possibilities for further research and development. Harnessing technology to involve as much of the population as possible in fun or game-like model development is another interesting topic.

Any type of mathematical model can be used to quantify resilience, as long as it gives us a measurement of how the system will respond to the disturbances of interest. The notion of desirability then allows us to quantify the degree of improvement or deterioration that will occur and thereby quantify resilience. Accordingly, resilience has been decoupled from basins of attraction, or from any mathematical artefacts of a specific type of model. Whether we have change that is sudden and shocking or slow and gradual, whether we have basins, attractors or not, we still want to be able to steward towards desirable and away from undesirable system features – we still want to be resilient.

Thus, application of the conceptual and mathematical frameworks in practice requires the operational framework presented in Chapter 5. This operational framework drew together theory and practice from resilience and adaptation, systems thinking, strategic planning and strength-based development. The process put forward is itself an intervention to build resilience.

The operational framework presented in Chapter 5 was applied to a case study of the resilience of agricultural communities on the Terai plains of Nepal in Chapter 6. This case study demonstrated that application of the operational framework for resilience, through the process presented in Chapter 5, was itself an intervention to build resilience. Through application of this process to understand and build resilience, the community is left with:

- Shared visions and aspirations for the future.
- Improved and expanded relationship networks.
- Mobilized resources.
- A plan for how to achieve their desired vision building on existing capacities within the community.
- Sensitivity to change and a greater capacity to cope with uncertainty.
- Critical thinking skills.
- Increased strategic capacity.

Scenario exercises are particularly useful for breaking down assumptions about the future that can hinder resilience and adaptive capacity by limiting the set of changes, disturbances and responses that any group of people is prepared to consider. They can be used at any level of planning and decision-making from individual, through household and community, all the way to regional and global levels – as the CCAFS SIRA and regional scenarios programs show. Scenarios can be used to provide the 'to what' in resilience planning activities and to build strategic capacity for decision-making under uncertainty.

The case study yielded a set of guidelines for participatory processes aimed at building resilience and adaptive capacity. These can be summarized as follows:

- Local ownership and leadership matter: The success or failure of various resilience or adaptation interventions over time relies upon local people having the will, resources and skills to carry them forward.
- Alignment with local values, visions and aspirations for the future is essential: no matter how excellent scientists, development practitioners or policymakers consider an intervention to be, if it is not what stakeholders want, they will not have the will or invest the resources and skills required to implement, maintain and live with it.
- Building resilience takes time: as with any development or change management process, change takes time and ongoing support is required.
- Succession planning and ongoing support is essential.
- Building on existing strengths in the community rather than relying on leveraging external knowledge and resources, and empowering the community to develop and seek its own self-identified solutions, is far more sustainable, particularly in the situation where continuous and ongoing external support is not consistently available. Thus people will ultimately have to rely on themselves. Focusing on leveraging external knowledge and

resources fosters dependence and this is a danger of individual technical-intervention-based, time-limited projects, unless they are contextualized as part of a broader, locally owned, ongoing community planning and development process.

- Learning by doing: the old adage, 'Tell me and I will forget, show me and I will remember, let me and I will understand', is true for adaptation learning. Thus, farmer-to-farmer learning by example and trial is excellent.
- Working with groups of people to facilitate resilience involves shared and reversed learning: the community teaches us about its needs, about what will work, what won't, and why. Accordingly, it is important to:
- Acknowledge different forms of knowledge, including local and traditional knowledge and different ways of obtaining knowledge in the success of any resilience or adaptation intervention.
- Each group of people is unique and options that work in one place may not work in another, even very close by, and even when many control variables are aligned. Thus, co-developing resilient pathways together with communities, based on existing strengths and drawing on suites of flexible options that can be tailored by groups of people themselves, to their particular needs, can be helpful.

Researching resilience requires working in collaborative interdisciplinary teams. It requires multiple perspectives; an in-depth knowledge of the many relevant topics in any given context that can only be provided by multiple people. Working with multiple stakeholders is essential, and multi-stakeholder processes require a team of researchers to facilitate, and interpret.

The Systemic Integrated Resilience and Adaptation (SIRA) research program was designed according to the operational framework presented in Chapter 5. It involves an interdisciplinary team. Throughout the SIRA program there were many instances of successful interdisciplinary collaboration, including the diagnostic and planning workshop described in Chapter 5, the scenario-exchange program described in Chapter 6 and the Ghana workshop described in Chapter 8. In the instances where there was collaboration, incredible achievements were obtained by everyone and by the program as a whole.

However, putting researchers from multiple disciplines together in a project is not enough to guarantee genuinely integrated interdisciplinary research. Long periods of time in the field together conducting shared action research activities, followed by structured dialogues, is also not enough to guarantee genuinely integrated interdisciplinary research in the team. While these two conditions are helpful, integrated applied interdisciplinary research remains challenging for the following reasons:

- External pressures and incentives
    - Individualistic academic performance measures, and a lack of performance measures incentivizing knowledge sharing and collaborative analyses.
    - Conflict of interest between novelty and societal relevance in academic performance measures and incentive structures.

- Theoretical and practical issues affecting integrating knowledge across disciplines.
    - Different disciplines have different ontological (theories about the way things are) and epistemological (theories about what we can know about the way things are) foundations; different ways of dealing with truth, complexity, diversity, pluralism; different ways of framing issues, different methods for generating and handling knowledge; different methods for arriving at decisions; different approaches to quality control and rigour; different standards about what constitutes data and evidence; and suggest different types of solutions.
    - Some disciplines perceived to have more legitimacy than others.
- Interpersonal dynamics which have a major effect on the research process and its outcomes:
    - Perceptions of particular biases held by one group member in the eyes of other group members make them more or less receptive to the perspectives of that group member.
    - Perceptions of agendas relating to power, control or self-promotion.
    - Interdisciplinary research requires a great deal of emotional intelligence.

Narrow self-interest works against collaboration. From this perspective, collaboration can be seen as an additional burden that interferes with individual research schedules. From another perspective, the collaboration could be seen as an opportunity to achieve novel contributions that could not have been otherwise reached.

In order to address these issues within the SIRA research program, we conducted two internal workshops, one focused directly on research integration and the other focused on Ghana, and facilitated a process in Ghana to co-develop integrated multi-level pathways to increase resilience and adaptive capacity. All of these activities were successful and provided unique insights. However, there is still a need for actions to be taken to enable resilience research more broadly:

- Motivate collaboration with the right incentives from the start of the program:
    - Incentivize collaboration with performance measures that reward knowledge-sharing and collaborative analyses and output development.
    - Motivate collaboration with stakeholders and the development of appropriate approaches and solutions by valuing societal relevance of research and reducing the focus on academic novelty.
- Provide training in:
    - Reflective practice and emotional intelligence.
    - Provide interdisciplinary practitioners with enough background in history and philosophy of science to navigate knowledge generation and negotiation in an interdisciplinary team.
        - Truth, Pluralism, Partial Views.
        - 'Critical appreciation of alien paradigms'.
        - Ability to critique the dominant paradigm in terms of pluralism, epistemology and ontology, in any so-called 'interdisciplinary' research program.

    - Incorporate this into courses for undergraduates, postgraduates and professionals.
- Increase time available in research programs for:
    - Building trust, understanding and relationships.
    - Sharing knowledge and understanding where the other person is coming from.
    - Reflective practices.

These are certainly areas for continued research and action in order to create safe spaces for interdisciplinary research to take place, with the right incentives and supported by training that is not currently standard in academia, but on which successful collaboration depends. These issues have hampered the progress of resilience research to date, resulting in some communities that have slipped back into technocratic approaches and few truly interdisciplinary collaborative studies. Implementing truly collaborative, interdisciplinary research is itself an area for further research.

There are many other areas for further development around the issue of involving more stakeholders in participatory modelling, sense-making, planning and decision-making processes. There are opportunities to use new technologies to involve a broader group of stakeholders in such processes. For example, the author is currently exploring the use of smartphone applications and games for involving the entire European public in scenario development around the resilience of European food systems. Another area for further research is in the way that citizen science in general can be used to contribute to understanding, measuring and managing system resilience. There is work to be done in further developing participatory modelling techniques that are accessible to stakeholders and yet accurately mathematically reflect those stakeholders' complex knowledge of the systems of interest. For example, the extensions of FCM and system dynamics models described above.

More research is required on the institutional and governance dimensions of resilience and adaptation. The challenges that exist with integrating research across disciplines exist with integrating governance across levels from local to global, as was shown by the Ghana Multi-level governance workshop. Further exploration of approaches for achieving this integration in a manner appropriate for different contexts around the world is needed. Some research has been done on network architectures that facilitate adaptive governance, but this is also an area for further research. The role of non-traditional actors including the private sector, in building resilience is also an area for further research.

There are limitless ways in which we can continue to think about how to understand, measure and manage the human and natural systems on which we depend. This is an ambitious task and it is impossible to comprehensively enumerate future research opportunities here. The author hopes to have covered a few stimulating options and hopes that you join her in striving to build the resilience of human and natural systems.

References

Ackoff, R. 1974. “Beyond Problem Solving.” Decision Sciences no. 5:10-15.

Ackoff, R. 1981. “The art and science of mess management.” Interfaces no. 2:20-26.

ACMHE. 2014.Association for Contemplative Mind in Higher Education 20142014]. Available from http://www.contemplativemind.org/programs/acmhe.

Ademiluyi, A. 2013.Farms of the Future Nepal Pilot: Farmers Voices, edited by CGIAR Climate Change Agriculture and Food Security Research Program. https://http://www.facebook.com/photo.php?v=361165310656028&set=vb.290278634411363&type=3&theater.

Adger, W. N. 2000a. “Institutional adaptation to environmental risk under transition in Vietnam.” Annals of the Association of American Geographers no. 90 (4):738-758.

Adger, W. N. 2000b. “Social and ecological resilience: are they related?” Progress in Human Geography (3):347-364.

Adger, W. N. 2003. “Social Capital, Collective Action, and Adaptation to Climate Change.” Economic Geography no. 79 (4):387-404.

Adger, W. N. 2006. “Vulnerability.” Global Environmental Change no. 16:268-281.

Adger, W. N., Arnell, N. W., and Tompkins, E. L. 2005. “Successful Adaptation to Climate Change Across Scales.” Global Environmental Change no. 15 (2):77-77.

Adger, W. N., Arnell, N. W., Tompkins, E. L., Dessai, S., Lu, X., Risbey, J. S., Conway, D., Thomas, D. S. G., Twyman, C., Noess, L. O., Bang, G., Eriksen, S., Vevatne, J., Brooks, N., Kelly, P. M., and Haddad, B. M. 2005. “Adaptation to climate change: perspectives across scales.” Global Environmental Change no. 15 (2):77-176.

Adger, W. N., Hughes, T. P., Folke, C., Carpenter, S. R., and Rockström, J. 2005. “Social-ecological resilience to coastal disasters.” Science no. 309:1036-1039.

Adger, W. N., Huq, S., Brown, K., Conway, D., and Hulme, M. 2003. “Adaptation to climate change in the developing world.” Progress in Development Studies no. 3 (3):179-195.

Adger, W. N., and Kelly, P. M. 1999. “Social Vulnerability to Climate Change and the Architecture of Entitlements.” Mitigation and Adaptation Strategies for Global Change no. 4 (3-4):253-266.

Agrawal, A. 2011. “Against mono-consequentialism: Multiple outcomes and their drivers in social–ecological systems.” Global Environmental Change no. 21:1-3.

Allenby, B., and Fink, J. 2005. “Toward Inherently Secure and Resilient Societies.” Science no. 309:1034-1036.

Allison, E. H., Andrew, N. L., and Oliver, J. 2007. "Enhancing the resilience of inland fisheries and aquaculture systems to climate change." ICRISAT Open Access Journal.

Alston, W. 1979. "Yes Virginia, there is a real world." Proceedings of the American Philosophical Association no. 52:779-808.

Anderies, J. M., Janssen, M. A., and Walker, B. H. 2002. "Grazing management, resilience, and the dynamics of a fire-driven rangeland system." Ecosystems no. 5:23-44.

Anderson, P. 1969. "Quote taken 25 September 1969." New Scientist:638.

Antonovsky, A., Maoz, B., Dowty, N., and Wijsenbeek, H. 1971. "Twenty-five years later: A limited study of the sequelae of the concentration camp experience." Social Psychiatry and Psychiatric Epidemiology no. 6 (4):186-193.

Armson, R. 2011. Growing Wings on the Way: Systems Thinking for Messy Situations. Devon: Triarchy Press.

Arrighi, G., and Silver, B. 2001. "Capitalism and world (dis)order." Review of International Studies no. 27 (5):257-279.

Ashby, W. R. 1973. "Some peculiarities of complex systems." Cybernetic Medicine no. 9:1-7.

Axelrod, R. 1976. Structure of Decision: the Cognitive Maps of Political Elites. Princeton, NJ, USA: Princeton University Press.

Bacon, F. 1620. The New Organon. Edited by L. Jardine and M. Silverthorne, Cambridge Texts in the History of Philosophy. Cambridge, UK: Cambridge University Press.

Bafana, B. 2011. Tool helps farmers anticipate their future climate. SciDevNet.

Bailey, M., Chaudhury, A., Helfgott, A., Sova, C., and Thorn, J. 2012. Farms of the Future: A Case Study from Nepal. CCAFS Report. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Barrett, C., and Swallow, B. 2006. "Fractal poverty traps." World Development no. 34 (1):1-15.
BBC News. 2007. In pictures: Anti-junta rallies in Burma.

Bean, N., Helfgott, A., and Lord, S. 2009. A Note on Quantitative Models of Resilience. Australia: Defence Science Technology Organisation, Australian Department of Defence.

Bechky, B. A. 2003. "Sharing meaning across occupational communities: The transformation of understanding on a production floor." Organization Science no. 14 (3):312-330.

Beisner, B. E., Haydon, D. T., and Cuddington, K. 2003. "Alternative stable states in ecology." Frontiers in Ecology and the Environment no. 1:376-382.

Bellwood, D. R., Hughes, T. P., Folke, C., and Nystrom, M. 2004. "Confronting the coral reef crisis." Nature no. 429:827-833.

Berche, B., von Ferber, C., Holovatch, T., and Holovatch, Y. 2009. "Resilience of Public Transport Networks Against Attacks." European Physical Journal B no. 71 (1):125-137.

Berkes, F., Colding, J., and Folke, C. 2003. Navigating Social–Ecological Systems: Building Resilience for Complexity and Change. Cambridge, UK: Cambridge University Press.

Berkes, F., and Folke, C. 1998. Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience. New York: Cambridge University Press.

Bhamra, R., Dani, S., and Burnard, K. 2011. "Resilience: the concept, a literature review and future directions." International Journal of Production Research no. 49 (18):5375-5393. doi: 10.1080/00207543.2011.563826.

Biggs, R., Carpenter, S. R., and Brock, W. A. 2009. "Turning back from the brink: Detecting an impending regime shift in time to avert it." Proceedings of the National Academy of Science in the United States of America no. 106 (3):826-831.

Birchall, J., and Ketilson, L. H. 2009. Resilience of the cooperative business model in times of crisis. In Sustainable Enterprise Program. Geneva: International Labour Office (ILO).

Bonabeau, E. 2002. "Agent-based modeling: Methods and techniques for simulating human systems." Proceedings of the National Academy of Sciences no. 99:7280– 7287.

Börjeson, L., Höjer, M., Dreborg, K.-H., Ekvall, T., and Finnveden, G. 2006. "Scenario types and techniques: Towards a user's guide." Futures no. 38 (7):723-739. doi: http://dx.doi.org/10.1016/j.futures.2005.12.002.

Bradley, J. T., Cloth, L., Hayden, R. A., Kloul, L., Reinecke, P., Siegle, M., Thomas, N., and Wolter, K. 2012. "Scalable Stochastic Modelling for Resilience." In Resilience Assessment and Evaluation of Computing Systems, edited by K. Wolter, Alberto Avritzer, Marco Vieira and Aad van Moorsel. Berlin, Heidelberg: Springer-Verlag.

Brand, F. S., and Jax, K. 2007. "Focusing the Meaning(s) of Resilience: Resilience as a Descriptive Concept and a Boundary Object." Ecology and Society no. 12 (1):23.

Broadbent, A. 2012. "Causes of causes." Philosophical Studies no. 158 (3):457-476.

Brock, W. A., and Carpenter, S. R. 2006. "Variance as a leading indicator of regime shift in ecosystem services." Ecology and Society no. 11 (2).

Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., Shinozuka, M., Tierney, K., Wallace, W. A., and Winterfeldt, D. v. 2003. "A framework to quantitatively assess and enhance the seismic resilience of communities." Earthquake Spectra no. 19 (4):733-752.

Brusatte, S. L., Butler, R. J., Barrett, P. M., Carrano, M. T., Evans, D. C., Lloyd, G. T., Mannion, P. D., Norell, M. A., Peppe, D. J., Upchurch, P., and Williamson, T. E. 2014. "The extinction of the dinosaurs." Biological Reviews.

Buckle, P., Marsh, G., and Smale, S. 2000. "New approaches to assessing vulnerability and resilience." Australian Journal of Emergency Managementno. 15:8-15.

Bueno, S., and Salmeron, J. L. 2009. "Benchmarking main activation functions in fuzzy cognitive maps." Expert Systems with Applications no. 36 (3):5221-5229.

Burke, M., Helfgott, A., and Lord, S. 2007. Robustness, Resilience and Adaptability: Implications for National Security, Safety and Stability. In DSTO Critical Infrastructure Protection Task. Australia: Defence Science Technology Organisation, Department of Defence.

Cabell, J. F., and Oelofse, M. 2012. "An indicator framework for assessing agroecosystem resilience." Ecology and Society no. 17 (1).

Campbell, F. C. 2008. Elements of Metallurgy and Engineering Alloys. United States of America: ASM International.

Carpenter, S. R. 2003. Regime shifts in lake ecosystems: pattern and variation. Vol. 15, Excellence in Ecology Series. Oldendorf/Luhe, Germany: Ecology Institute.

Carvalho, J. P., and Tome, J. A. B. 2001. Rule Base Fuzzy Cognitive Maps and Fuzzy Cognitive Maps – A Comparative Study. Paper read at 10th IEEE International Conference on Fuzzy Systems.

CCAFS. 2014. Climate Analogues 20122014]. Available from http://ccafs.cgiar.org/climate-analogues - .U_2FXlaZb1o.

CCAFS. 2014. Regional Scenarios. CGIAR Climate Change Agriculture and Food Security Research Program 2014a2014]. Available from http://www.ccafs.cgiar.org/scenarios.

CCAFS. 2014. Systemic Integrated Resilience and Adaptation. CGIAR Climate Change, Agriculture and Food Security Research Program 2014b2014].

Chan, N. H., and Wong, H. Y. 2007. "Data mining of resilience indicators." IIE Transactions no. 39:617-627.

Chaudhury, M., Vervoort, J., Kristjanson, P., Ericksen, P., and Ainslie, A. 2012. "Participatory scenarios as a tool to link science and policy on food security under climate change in East Africa." Regional Environmental Change:1-10.

Checkland, P. 1981. Systems Thinking, Systems Practice. Chichester: Wiley.

Checkland, P. 1999. Soft Systems Methodology: A Thirty Year Retrospective. Chichester, UK: Wiley.

Churchman, C. W. 1968a. Challenge to Reason. New York: McGraw-Hill.

Churchman, C. W. 1968b. The Systems Approach. New York, USA: Dell.

Cicchetti, D., and Blender, J. A. 2004. "A multiple-levels-of-analysis approach to the study of developmental processes in maltreated children." Proceedings of the National Academy of Science in the United States of America no. 101 (50):17325-17326.

Cicchetti, D., and Blender, J. A. 2006. "A multiple-levels-of-analysis perspective on resilience: implications for the developing brain, neural plasticity, and preventative interventions." Annals of the New York Academy of Sciences no. 1094:248-258.

Cimellaro, G. P., Reinhorn, A. M., and Bruneau, M. 2010. "Framework for analytical quantification of disaster resilience." Engineering Structures no. 32 (11):3639-3649.

Cole, K. C. 2009. Something Incredibly Wonderful Happens: Frank Oppenheimer and the World He Made Up. New York: Houghton Mifflin Harcourt.

Collings, J. B., and Wollkind, D. J. 1990. "A global analysis of a temperature-dependent model system for a mite predator-prey interaction." SIAM J Appl Math no. 50 (5):1348-1372.

Copperrider, D., and Whitney, D. 1999. "Appreciative Inquiry: A positive revolution in change. " In The Change Handbook, edited by P. Holman and T. Devane. Berrett-Koehler Publishers Inc.

Copperrider, D. L., and Srivastva, S. 1987. "Appreciative Inquiry in Organizational Life." In Research in Organisational Change and Development, edited by W. Pasmore and R. Woodman, 129-169. Greenwich: JAI Press Inc.

Council of Australian Governments. 2009. National Strategy for Disaster Resilience.

Credit Suisse. 2013. Global Wealth Report. Zurich: Credit Suisse.

Cumming, G. S., Barnes, G., Perz, S., Schmink, M., Sieving, K. E., Southworth, J., Binford, M., Holt, R. D., Stickler, C., and Holt, T. V. 2005. "An Exploratory Framework for the Empirical Measurement of Resilience." Ecosystems no. 8:975-987.

Cumming, G. S., and Collier, J. 2005. "Change and identity in complex systems." Ecology and Society no. 10 (1).

Cutter, S., Burton, C., and Emrich, C. 2010. "Disaster resilience indicators for benchmarking baseline conditions." Journal of Homeland Security and Emergency Managementno. 7 (1):1-22.

Dai, L., Vorselen, D., Korolev, K. S., and Gore, J. 2012. "Generic Indicators for Loss of Resilience Before a Tipping Point Leading to Population Collapse." Science no. 336 (6085):1175-1177.

Dakos, V., Scheffer, M., Nes, E. H. v., Brovkin, V., Petoukhov, V., and Held, H. 2008. "Slowing down as an early warning signal for abrupt climate change." Proceedings of the National Academy of Science in the United States of America no. 105 (38):14308-14312.

Danter, K. J., Griest, D. L., Mullins, G. W., and Norland, E. 2000. "Organizational change as a component of ecosystem management." Society and Natural Resource no. 13:537–547.

Darwin, C. 1859. On the Origin of Species by Means of Natural Selection. London: John Murray.

Dawkins, R. 1983. "Universal Darwinism." In Evolution from Molecules to Men, edited by D.S. Bendall. Cambridge, UK: Cambridge University Press.

DeAngelis, D. L. 1980. "Energy flow, nutrient cycling, and ecosystem resilience." Ecology no. 61 (4):764-771.

Deffuant, G., and Gilbert, N. 2011. Viability and Resilience of Complex Systems: Concepts, Methods and Case Studies from Ecology and Society, Understanding Complex Systems. Berlin Heidelberg: Springer-Verlag.

Dekker, S., Hollnagel, E., Woods, D., and Cook, R. 2008. Resilience Engineering: New directions for measuring and maintaining safety in complex systems. Lund, Sweden: Lund University School of Aviation.

Dessai, S., Lu, X., and Risbey, J. S. 2005. "On the role of climate scenarios for adaptation planning." Global Environmental Change no. 15 (2):87-97. doi: http://dx.doi.org/10.1016/j.gloenvcha.2004.12.004.

Diamond, J. 2005. Collapse: How Societies Choose to Fail or Survive. Camberwell, Victoria Penguin.

Dorbritz, R. 2011. Assessing the resilience of transportation systems in case of large scale disastrous events. Paper read at 8th International Conference on Environmental Engineering, at Vilnius, Lithuania.

Doyle, J. C., Alderson, D., Li, L., Low, S., Roughan, M., Shalunov, S., Tanaka, R., and Willinger, W. 2005. "The "Robust Yet Fragile" Nature of the Internet." Proceedings of the National Academy of Sciences of the United States of America no. 102 (41):14497-14502.

Doyle, J. C., Alderson, D. L., Li, L., Low, S., Roughan, M., Shalunov, S., and Tanaka, R. 2005. "The "robust yet fragile" nature of the internet." Proceedings of the National Academy of Sciences no. 102 (41):14497-14502.

Doyle, M., and Drew, C. 2008. Large scale ecosystem restoration: Five case studies from the United States. Washington DC: Island Press.

Drake, J. M., and Griffen, B. D. 2010. "Early warning signals of extinction in deteriorating environments." Nature no. 467:456–459.

Drury, K. L. S., and Lodge, D. M. 2009. "Using mean first passage times to quantify equilibrium resilience in perturbed intraguild predation systems." Theoretical ecology no. 2:41-51.

Eakin, H., Tompkins, E., Nelson, D. R., and Anderies, J. M. 2009. "Hidden costs and disparate uncertainties: Trade-offs involved in Approaches to Climate Policy." In Adapting to climate change: thresholds, values, and governance, edited by W. N. Adger, I. Lorenzoni and K. O'Brien, 212-226. Cambridge: Cambridge University Press.

Elbow, P., and Shapiro, A. Critical Thinking Training 2011. Available from http://www.teachablemoment.org/high/criticalthinking.html.

Ercal, G., and Matta, J. 2013. "Resilience Notions for Scale-Free Networks." Procedia Computer Science no. 20:510-515.

European Commission. 2012. The EU Approach to Resilience. Brussels: Communication from the European Commission to the European Parliament and the Council.

Folke, C. 2006. "Resilience: The emergence of a perspective for social-ecological systems analyses." Global Environmental Change no. 16:253-267.

Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., and Rockström, J. 2010. "Resilience thinking: integrating resilience, adaptability and transformability." Ecology and Society no. 15 (4).

Folke, C., Carpenter, S. R., Walker, B. H., Scheffer, M., Elmqvist, T., Gunderson, L. H., and Holling, C. S. 2004. "Regime shifts, resilience and biodiversity in ecosystem management." Annual Review in Ecology, Evolution and Systematics no. 35:557-581.

Folke, C., Colding, J., and Berkes, F. 2003. "Synthesis: building resilience and adaptive capacity in social–ecological systems." In Navigating Social–Ecological Systems: Building Resilience for Complexity and Change, edited by F. Berkes, J. Colding and C. Folke. Cambridge: Cambridge University Press.

Folke, C., Hahn, T., Olsson, P., and Norberg, J. 2005. "Adaptive governance of social–ecological systems." Annual Review of Environment and Resources no. 30:441-473.

Foster, M., and Mathie, A. 2001. Situating Asset-Based Community Development in the International Development Context.

Frankhauser, S., and Tol, R. S. J. 1997. "The social costs of climate change: the IPCC second assessment report and beyond." Mitigation and Adaptation Strategies for Global Change no. 1:385-403.

Fraser, E. D. G. 2003. "Social vulnerability and ecological fragility: building bridges between social and natural sciences using the Irish Potato Famine as a case study." Conservation Ecology no. 7 (2).

Fraser, E. D. G., Mabee, W., and Figge, F. 2005. "A framework for assessing the vulnerability of food systems to future shocks." Futures no. 37:465-479.

Freckleton, D., Heaslip, K., Louisell, W., and Collura, J. 2012. Evaluation of transportation network resiliency with consideration for disaster magnitude. Paper read at The 91st Annual Meeting of the Transportation Research Board, at Washington DC, USA.

Fuchs, S. 2001. Against Essentialism. USA: President and Fellows of Harvard College.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., and Trow, M. 1994. The new production of knowledge: the dynamics of science and research in contemporary societies. London: Sage.

Gibson, C., Ostrom, E., and Ahn, T. K. 2000. "The concept of scale and the human dimensions of global change: a survey." Ecological Economics no. 32 (2):217-239.

Glaser, B., and Strauss, A. 1967. The Discovery of Grounded Theory. Chicago: Aldine.

Glykas, M. 2010. Fuzzy Cognitive Maps: Theory, Methodologies, Tools and Applications. New York: Springer.

Gotts, N. M. 2007. "Resilience, panarchy, and world-systems analysis." Ecology and Society no. 12 (1).

Government of Nepal. 2010. Nepal: Stategic Program for Climate Resilience. edited by Asian Development Bank, International Finance Corporation and World Bank.

Gray, D. 2014. The Beginning of the Disciplines 20092014]. Available from https://http://www.flickr.com/photos/davegray/4129451298/.

Gray, S., Chan, A., Clark, D., and Jordan, R. C. 2012. "Modeling the integration of stakeholder knowledge in social-ecological system decision-making: Benefits and limitations to knowledge diversity." Ecological Modelling no. 229:88-96.

Gray, S., Gray, S., Kok, J.-L. D., O'dwyer, B., Jordan, R., Helfgott, A., and Nyaki, A. 2014. "Using Fuzzy Cognitive Mapping as a Participatory Approach to Measure Resilience, Change, and Preferred States of Social-ecological Systems." Ecology and Society no. Submitted.

Gray, S. A., Gray, S., Cox, L. J., and Henly-Shepard, S. 2013. Mental Modeler: A Fuzzy-Logic Cognitive Mapping Modeling Tool for Adaptive Environmental Management. Paper read at Hawaii International Conference on Systems Sciences.

Gray, S. A., Zanre, E., and Gray, S. R. J. 2014. "Fuzzy Cognitive Maps as Representations of Mental Models and Groups." In Fuzzy Cognitive Maps for Applied Sciences and Engineering, edited by E. I. Papageorgiou. Berlin Heidelberg: Springer-Verlag.

Green, A. L., and Bellwood, D. 2009. Monitoring Functional Groups of Herbivorous Reef

Fishes as Indicators of Coral Reef Resilience: A practical guide for coral reef managers in the Asia Pacific Region. IUCN, Gland, Switzerland: IUCN working group on Climate Change and Coral Reefs.

Gregory, W. 1992. Critical Systems Thinking and Pluralism: A New Constellation, City University, London.

Gregory, W. 1996a. "Dealing with Diversity." In Critical Systems Thinking: Current Research and Practice, edited by R. Flood and N. Romm. New York, U. S. A. : Plenum.

Gregory, W. 1996b. "Discordant pluralism: a new strategy for critical systems thinking?" Systems Practice no. 9:605-625.

Grisogono, A. 2005. "Co-Adaptation." SPIE Symposium on Microelectronics, MEMS and Nanotechnology no. 6039-1.

Grothman, T., and Patt, A. 2005. "Adaptive capacity and human cognition." Global Environmental Change no. 15:199-213.

Grumbine, R. E. 1994. "What is ecosystem management?" Conservation Biology no. 8:27-38.

Gunderson, L. H. 2000. "Ecological Resilience — In Theory and Application." Annual Review of Ecology & Systematics no. 31.

Gunderson, L. H., and Holling, C. S. 2002. Panarchy: Understanding Transformations in Human and Natural Systems. Washington D. C., U. S. A.: Island Press.

Gunderson, L. H., and Pritchard, L. 2002. Resilience and the Behaviour of Large Scale Ecosystems. Vol. 60, SCOPE. Washington DC, USA: Island Press.

Hall, J., and Hammond, S. 1998. What is Appreciative Inquiry?: Thin Book Publishing.

Hallegatte, S., Hourcade, J.C., and Ambrosi, P. 2007. "Using climate analogues for assessing climate change economic impacts in urban areas." Climatic Change no. 82 (1):47-60.

Hamel, G., and Valikangas, L. 2003. "The quest for resilience." Harvard Business Review no. 81 (9):52-65.

Hammond, J. S., K.Keeney, R., and Raifa, H. 1999. Smart Choices: A Practical Guide to Making Better Decisions. Boston, MA, USA: Harvard Business School Press.

Hazell, P. B. R., and Rahman, A. 2014. New Directions for Smallholder Agriculture. Vol. 2014. Oxford, UK: Oxford University Press.

Heaslip, K., Louisell, W. C., Collura, J., and Serulle, N. U. 2010. "A sketch level method for assessing transportation network resiliency to natural disasters and man-made events". Paper read at The 89th Annual Meeting of the Transportation Research Board, at Washington D.C., U.S.A.

Held, H., and Kleinen, T. 2004. "Detection of climate system bifurcations by degenerate fingerprinting." Geophysical Research Letters no. 31.

Helfgott, A. 2006. "Mistakes With Maps" A Critique of Resilience, Adaptability and Transformability in Social-Ecological Systems. In Robustness, Resilience and Adaptability: Implications for National Security, Safety and Stability. Australia: Defence Science Technology Organisation, Department of Defence.

Helfgott, A. 2008. "Situating Strength-Based Approaches to Community Development in a Systems Thinking Context: The Cambodia Tales." The Systemist no. 30 (2).

Helfgott, A., Bailey, M., Sova, C., Thorn, J., Chaudhury, A., Vervoort, J., Upraity, V., Ademiluyi, A., Kok, K., and Aggarwal, P. 2014. "Exploratory Exchanges and Farms of the Future." Technological Forecasting and Social Change no. Submitted.

Helfgott, A., Bean, N., Lord, S., Wildenberg, M., Gray, S., Gray, S., Vervoort, J., Kok, K., and Ingram, J. 2014. "Clarifying Fuzziness: Fuzzy Cognitive Maps, Neural Networks and System Dynamics Models in Participatory Social and Environmental Decision-aiding Processes." Global Environmental Change no. Submitted.

Helfgott, A., and Burke, M. 2006. Overview of Conceptual Model. Adelaide, Australia: Defence, Science Technology Organisation, Australian Department of Defence.

Helfgott, A., and Lord, S. 2006. Towards a Core Conceptual Model of Resilience, Robustness and Adaptability. Adelaide, Australia: Defence Science, Technology Organisation, Australian Department of Defence.

Helfgott, A., Sova, C., Chaudhury, A., Thorn, J., and Bailey, M. In preparation. "Systemic Integrated Resilience and Adaptation." Ecology and Society.

Helfgott, A., Vervoort, J., and Bailey, M. 2014. Systemic Integrated Resilience and Adaptation (SIRA) Diagnostic, Prioritization and Planning Toolkit: A guidebook for researchers and practitioners working with stakeholders. Copenhagen, Denmark: CGIAR Climate Change Agriculture and Food Security Research Program.

Hodgson, A. M. 2008. "The Restoration of Community Resilience: An alcohol and drugs perspective." The Systemist no. 30 (2):422-434.

Holling, C. S. 1961. "Principles of insect predation." Annual Review of Entomology no. 6:163-182.

Holling, C. S. 1973. "Resilience and stability of ecological systems." Annual Review of Ecology and Systematics no. 4:1-23.

Holling, C. S. 1996. "Engineering Resilience versus Ecological Resilience." In Engineering Within Ecological Constraints, edited by Peter C. Schulze. Washington, D.C.: National Academy of Engineering, National Academy Press.

Holling, C. S., Gunderson, L., and Peterson, G. 2002. “Sustainability and Panarchies.” In Panarchy: Understanding Transformations in Human and Natural Systems, edited by L.H. Gunderson and C.S. Holling, 63-102. Washington DC, USA: Island Press.

Holling, C. S., and Gunderson, L. H. 2002. “Resilience and adaptive cycles.” In Panarchy: understanding transformations in human and natural systems, edited by L. H. Gunderson and C. S. Holling, 25-62. Washington D.C., USA: Island Press.

Holling, C. S., and Sanderson, S. 1996. “Dynamics of (dis)harmony in ecological and social systems.” In Rights to Nature: Ecological, Economic, Cultural, and Political Principles of Institutions for the Environment, edited by S. S. Hanna, C. Folke and K. G. Maler, 57-85. Washington DC, USA: Island Press.

Hughes, T. P. 1994. “Catastrophes, Phase Shifts, and Large-Scale Degradation of a Caribbean Coral Reef.” Science no. 265 (5178):1547-1551.

Hughes, T. P., Ghaham, N. A. J., Jackson, J. B. C., Mumby, P. J., and Steneck, R. S. 2010. “Rising to the challenge of sustaining coral reef resilience.” Trends in Ecology and Evolution no. 25:633-642.

Hughes, T. P., Gunderson, L. H., Folke, C., Baird, A. H., Bellwood, D., Berkes, F., Crona, B., Helfgott, A., Leslie, H., Norberg, J., Nystrom, M., Olsson, P., Osterblom, H., Scheffer, M., Schuttenberg, H., Steneck, R. S., Tengo, M., Troell, M., Walker, B., Wilson, J., and Worm, B. 2007. “Adaptive Management of the Great Barrier Reef and the Grand Canyon World Heritage Areas.” Ambio no. 36 (7).

Hulme, M. 2009. Why We Disagree About Climate Change: Understanding Controversy, Inaction and Opportunity. Cambridge, United Kingdom: Cambridge University Press.

Huub Dijstelbloem, Frank Huisman, Frank Miedema, and Mijnhardt, W. 2014. Science in Transition Status Report: Debate, progress and recommendations. Utrecht, The Netherlands: Science in Transition.

Ingram, J. 2013. CIMSANS Food Systems Diagram. University of Oxford.

International Federation of Red Cross and Red Crescent Societies. 2004. ICRC Assistance Policy. ICRC.

International Federation of Red Cross and Red Crescent Societies. 2012. Understanding community resilience and program factors that strengthen them: Development). A comprehensive study of Red Cross Red Crescent Societies tsunami operation’ (Geneva, International Federation). Geneva, Switzerland: International Federation of Red Cross and Red Crescent Societies.

IPCC. 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability (Working Group II contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change). Cambridge University Press: Intergovernmental Panel on Climate Change.

IPCC AR4 SYR. 2007. Climate Change 2007: Synthesis Report, Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,edited by IPCC Core Writing Team, R.K Pachauri and A. Reisinger.

Ison, R. L. 2008. "Systems thinking and practice for action research." In The Sage Handbook of Action Research Participative Inquiry and Practice, edited by Peter W. Reason and Hilary Bradbury, 139–158. London, UK: Sage Publications.

Jabeen, H., Johnson, C., and Allen, A. 2010. "Built-in resilience: learning from grassroots coping strategies for climate variability." Environment and Urbanization no. 22.

Jackson, M. C. 1987. "New Directions in Management Science." In New Directions in Management Science, edited by M.C. Jackson and P. Keys. Aldershot, UK: Gower.

James, W. 1909. The Meaning of Truth. Cambridge, USA: Harvard University Press.

Janssen, M. A., Anderies, J. M., and Walker, B. H. 2004. "Robust strategies for managing rangelands with multiple stable attractors." Journal of Environmental Economics and Management no. 47:140-162.

Janssen, M. A., T. A, K., and M.Scheffer. 2003. "Sunk-cost effects and vulnerability to collapse in ancient societies." Current Anthropology no. 44:722-728.

Jerome. 2014. Schild 20132014]. Available from http://www.humo.be/jeroom/2835/batch2013apr-schild-def-jpg.

Jones, L., Ludi, E., and Levine, S. 2010. Towards a characterisation of adaptive capacity: a framework for analysing adaptive capacity at the local level. London, UK: Overseas Development Institute.

Kant, I. 1787. The Critique of Pure Reason. Translated by N. K. Smith. 2nd Edition ed. Basingstoke: Macmillian.

Keogh, B. K., and Weisner, T. 1993. "An ecocultural perspective on risk and protective factors in children's development : Implications for learning disabilities." Learning Disabilities Research and Practice no. 8:3-10.

Kirmayer, L. J., Sehdev, M., Whitley, R., Dandeneau, S.. F., and Isaac, C. 2009. "Community Resilience: Models, Metaphors and Measures." Journal of Aboriginal Health no. 5 (1).

Klasen, F., Oettingen, G., Daniels, J., Post, M., Hoyer, C., and Adam, H. 2010. "Posttraumatic resilience in former ugandan child soldiers." Child Development no. 81 (4):1096-1113.

Klausmeier, C. A. 2001. "Habitat destruction and extinction in competitive and mutualistic metacommunities." Ecology Letters no. 4:57-63.

Klein, R. J. T., Nicholls, R. J., and Thomalla, F. 2003. "Resilience to natural hazards: How useful is this concept?" Global Environmental Change Part B: Environmental Hazards no. 5 (1–2):35-45. doi: http://dx.doi.org/10.1016/j.hazards.2004.02.001.

Kline, S. J. 1995. Conceptual Foundations for Multidisciplinary Thinking. Stanford, California: Standford University Press.

Knight, C. J. K., Boyd, D. J. B., and Penn, A. S. 2014. "Linear and sigmoidal fuzzy cognitive maps: An analysis of fixed points." Applied Soft Computing no. 15:193-202.

Kok, K. 2009. "The potential of Fuzzy Cognitive Maps for semi-quantitative scenario development with an example from Brazil." Global Environmental Change no. 19:122-133.

Kok, K., van Vliet, M., Bärlund Ilona, I., Dubel, A., and Sendzimir, J. 2011. "Combining participative backcasting and exploratory scenario development: Experiences from the SCENES project." Technological Forecasting and Social Change no. 78 (5):835-851.

Kontogianni, A. D., Papageorgiou, E. I., and Tourkolias, C. 2012. "How do you perceive environmental change? Fuzzy Cognitive Mapping informing stakeholder analysis for environmental policy making and non-market valuation." Applied Soft Computing no. 12:3725-3735.

Kopf, S., Ha-Duong, M., and Hallegate, S. 2008. "Using maps of city analogues to display and interpret climate change scenarios and their uncertainty." Nat. Hazards Earth Syst. Sci. no. 8 (905-918).

Kosko, B. 1986. "Fuzzy Cognitive Maps." International Journal of Man-Machine Studies no. 24:65-75.

Kosko, B. 1988. "Hidden Patterns in Combined Adaptive Knowledge Networks." International Journal of Approximate Reasoning no. 2:377-393.

Kosko, B. 1990. "Fuzziness Versus Probability." International Journal of General Systems no. 17:211-240.

Kretzmann, J. P., and McKnight, J. L. 1993. Building Communities from the Inside Out: A path toward finding and mobilizing a community's assets.ACTA Publications.

Kriegler, E., Hall, J. W., Held, H., Dawson, R., and Schellnhuber, H. J. 2009. "Imprecise probability assessment of tipping points in the climate system." Proceedings of the National Academy of Science in the United States of America no. 106 (13):5041-5046.

Lade, S. J., Tavoni, A., Levin, S., and Schlüter, M. 2013. "Regime Shifts in a social-ecological system." Theoretical Ecology no. 6:359-372.

Laurance, W. F., Dell, B., Turton, S. M., Lawes, M. J., Hutley, L. B., McCallum, H., Dale, P., Bird, M., Hardy, G., Prideaux, G., Gawne, B., McMahon, C. R., Yu, R., Hero, J.-M., Schwarzkopf, L., Krockenberger, A., Douglas, M., Silvester, E., Mahony, M., Vella, K., Saikia, U., Wahren, C.-H., Xu, Z., Smith, B., and Cocklin, C. 2011. "The 10 Australian ecosystems most vulnerable to tipping points." Biological Conservation no. 144:1472-1480.

Leach, M. 2008. Re-framing Resilience: a Symposium Report. In STEPS Working Paper. Brighton, UK: STEPS Centre.

Lenton, T. M., Livina, V. N., Dakos, V., van Nes, E. H., and Scheffer, M. 2009. "Early warning of climate tipping points from critical slowing down: comparing methods to improve robustness." Philosophical Transactions of the Royal Society no. 367:871-884.

Leu, L., Abbass, H., and Curtis, N. 2010. Resilience of ground transportation networks: A case study on Melbourne. Paper read at 33rd Australiasian Transport Research Forum Conference, at Canberra, Australia.

Levin, S. 1998. "Ecosystems and the biosphere as complex adaptive systems." Ecosystems no. 1 (5):431-436.

Levine, S., Pain, A., Bailey, S., and Fan, L. 2012. The relevance of 'resilience'? In Policy Brief 49, edited by Humanitarian Policy Group. United Kingdom: Overseas Development Institute.

Lewes, G. 1875. Problems of Life and Mind. London UK: Kegan Paul.

Lewis, D. 1973. "Causation." Journal of Philosophy no. 70:556-567.

Lewontonin, R. C. 1969. "The meaning of stability." In Diversity and Stability of Ecological Systems. Brookhaven, New York: Brookhaven Symposia in Biology.

Lilienfield, R. 1978. The Rise of Systems Theory: An Ideological Analysis. New York, U. S. A.: Wiley.

Locke, J. 1689. Two Treatises of Government. 1967 ed. Cambridge: Cambridge University Press.

Lord, S. 2007a. Mathematical Framework of Resilience. In Robustness, Resilience and Adaptability: Implications for National Security, Safety and Stability. Adelaide, Australia: Defence Science, Technology Organisation, Australian Department of Defence.

Lord, S. 2007b. Mathematical Framework of Resilience: Discrete. In Robustness, Resilience and Adaptability: Implications for National Security, Safety and Stability. Adelaide, Australia: Defence Science, Technology Organisation, Australian Department of Defence.

Lord, S. 2007c. Mathematical Framework of Resilience: Summary. In Robustness, Resilience and Adaptability: Implications for National Security, Safety and Stability. Adelaide, Australia: Defence Science, Technology Organisation, Australian Department of Defence.

Ludwig, D., B. Walker, and C. S. Holling. 1997. "Sustainability, stability, and resilience." Conservation Ecology no. 1:1.

Luthar, S., and Cicchetti, D. 2000. "The construct of resilience: Implications for interventions and social policies." Development and psychopathology no. 12 (4):857–885.

Mackie, J. L. 1980. The Cement of the Universe: A Study of Causation. Oxford, UK: Oxford University Press.

Maguire, B., and Hagan, P. 2007. Disasters and Communities: Understanding Social Resilience. Canberra, Australia: Defence Science Technology Organisation, Australian Department of Defence.

Majer, J. D. 1990. "Rehabilitation of Disturbed Land." In Australian Ecosystems: 200 Years of Utilization, Degredation and Reconstruction, edited by D.A. Saunders, A.J.M. Hopkins and R.A. Howe, 509-519. Australia: Ecological Society of Australia.

Martin, S. 2004. "The cost of restoration as a way of defining resilience: a viability approach applied to a model of lake eutrophication." Ecology and Society no. 9 (2):8.

Martin, S., Deffuant, G., and Calabrese, J. M. 2011. "Defining Resilience Mathematically: From Attractors to Viability." In Viability and Resilience of Complex Systems: Concepts, Methods and Case Studies from Ecology and Society, edited by Guillaume Deffuant and Nigel Gilbert.

Martin-Breen, P., and Anderies, J. M. 2011. Resilience: A Literature Review. Rockefeller Foundation.

Marx, K. 1887. Capital: A Critique of Political Economy. Translated by S. Moore and E. Aveling. 4th ed. Vol. 1. London: Lawrence and Wishart.

Masten, A. 2001. "Ordinary magic: Resilience processes in development." American psychologist no. 56 (3):227.

Masten, A. S. 2010. Ordinary Magic: Lessons from Research on Resilience in Human Development. edited by Education Canada: Canada Education Association.

Matsinos, Y. G., and Troumbis, A. Y. 2002. "Modeling competition, dispersal and effects of disturbance in the dynamics of a grassland community using a cellular automaton." Ecological Modelling no. 149:71-83.

Matthews, D. 2004. Rethinking Systems Thinking, University of Adelaide, Adelaide.

May, R. M. 1977. "Thresholds and breakpoints in ecosystems with a multiplicity of stable states." Nature no. 269:471-477.

McAnany, P. A., and Yoffee, N. 2009. Questioning Collapse: Human Resilience, Ecological Vulnerability, and the Aftermath of Empire. Cambridge: Cambridge University Press.

McIntosh, R. J. 2000. "Social memory in Mande." In The Way the Wind Blows: Climate, History, and Human Action, edited by R.J. McIntosh, J.A. Tainter and S.K. McIntosh. New York: Columbia University Press.

Meadows, D. 1994. Envisioning a Sustainable Future. Paper read at International Society for Ecological Economics, at San Jose, Costa Rica.

Mermet, L. 2011. Strategic Environmental Management Analysis: Addressing the Blind Spots of Collaborative Approaches. In Pour le debat. Paris: Institut du développement durable et des relations internationales.

Midgley, G. 2000a. Systemic Intervention: Philosophy, Methodology and Practice, Contemporary Systems Thinking. New York: Kluwer Academic.

Midgley, G. 2000b. Systemic intervention: philosophy, methodology, and practice: Springer.

Midgley, G. 2003. Systems Thinking, Sage Library in Business and Management: Sage Publications.

Midgley, G., and Ochoa-Arias, A. E. 1999. "Visions of community for community OR " International Journal of Management Science no. 27:259-274.

Midgley, G., and Richardson, K. A. 2007. "Systems thinking for community involvement in policy analysis ".E:CO no. 9 (1-2):167-183.

Mikkelsen, B. 2005. Methods For Development Work and Research: A New Guide for Practitioners. New Delhi: Sage Publications.

Mikkelson, G. M., Gonzalez, A., and Peterson, G. D. 2007. "Economic Inequality Predicts Biodiversity Loss." PLoS ONE no. 2 (5).

Mill, J. S. 1859. On Liberty. 1974 ed. Harmondsworth: Penguin.

Moss, R. H., Edmonds, J. A., Hibbard, K. A., Manning, M. R., Rose, S. K., Vuuren, D. P. v., Carter, T. R., Emori, S., Kainuma, M., Kram, T., Meehl, G. A., Mitchell, J. F. B., Nakicenovic, N., Riahi, K., Smith, S. J., Stouffer, R. J., Thomson, A. M., Weyant, J. P., and Wilbanks, T. J. 2010. "The next generation of scenarios for climate change research and assessment." Nature no. 463.

Murray, R. M., Sastry, S. S., and Li, Z. 1994. A Mathematical Introduction to Robotic Manipulation. Boca Raton, FL, USA: CRC Press Inc.

Nelson, D. R., Adger, W. N., and Brown, K. 2007. "Adaptation to Environmental Change: Contributions of a Resilience Framework." Annual Review of Environment and Resources no. 32 (1):395-419. doi: 10.1146/annurev.energy.32.051807.090348.

Neubert, M. G., and Caswell, H. 1997. "Alternatives to resilience for measuring the responses of ecological systems to perturbations." Ecology no. 78 (3):653-665.

Norris, F. H., Stevens, S. P., Pferfferbaum, B., Wyche, K. F., and Pfefferbaum, R. L. 2008. "Community Resilience as a Metaphor, Theory, Set of Capacities, and Strategy for Disaster Readiness." American Journal of Community Psychology no. 41 (1-2):127-150.

Nystrom, M., and Folke, C. 2001. "Spatial resilience of coral reefs." Ecosystems no. 4:406-417.

Nystrom, M., Folke, C., and Moberg, F. 2000. "Coral reef disturbance and resilience in a human-dominated environment." Trends in Ecology and Evolution no. 15:413-417.

O Neill, B. C., MacKellar, F. L., and Lutz, W. 2001. Population and climate change. Cambridge: Cambridge University Press.

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L., and West, J. 2004. "Mapping vulnerability to multiple stressors: climate change and globalization in India." Global Environmental Change no. 14:303-313.

Olick, J. K., and Robbins, J. 1998. "Social memory studies: from 'collective memory' to historical sociology of mnemonic practices." Annual Review of Sociology no. 24:105-140.

Olsson, P., Folke, C., and Berkes, F. 2004. "Adaptive Comanagement for Building Resilience in Social–Ecological Systems." Environmental Management no. 34 (1):75-90. doi: 10.1007/s00267-003-0101-7.

OpenCV API Reference. 2014. Neural Networks. In Machine Learning.

Orians, G. H. 1975. "Diversity, stability and maturity in natural ecosystems." In Unifying Concepts in Ecology, edited by W.H. van Dobben and R.H. lowe-McConnell, 139-150. The Hague: Junk.

Ortiz, M., and Wolff, M. 2002. "Dynamical simulation of mass-balace trophic models for benthic communities of north-central Chile: assessment of resilience time under alternative management scenarios." Ecological Modelling no. 148:277-291.

Ostrom, E. 2005. Understanding Institutional Diversity. Princeton, USA: Princeton University Press.

Ostrom, E., and Ahn, T. K. 2003. Foundations of Social Capital. Cheltenham, UK: Edward Elgar.

Ott, K. 2003. "The case for strong sustainability." In Greifswald's environmental ethics, edited by and P. P. Thapa K. Ott. Greifswald, Germany: Steinbecker Verlag Ulrich Rose.

Oxfam International. 2005. The Tsunami's Impact on Women. In Oxfam Briefing Note. Oxford, UK: Oxfam International.

Oxford English Dictionary. 2012. Oxford: Oxford University Press.

Ozesmi, U., and Ozesmi, S. L. 2004. "Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach." Ecological Modelling no. 176:43-64.

Page, S. E. 2011. Diversity and Complexity. Princeton, New Jersey, U. S. A. : Princeton University Press.

Papageorgiou, E. 2014. Fuzzy Cognitive Maps for Applied Sciences and Engineering, Intelligent Systems Reference Library. Berlin Heidelberg: Springer Verlang.

Papageorgiou, E., and Salmeron, J. L. 2013. "A Review of Fuzzy Cognitive Maps Research During the Last Decade." IEEE Transactions on Fuzzy Systems no. 21:66-79.

Papageorgiou, E. I., and Salmeron, J. L. 2014. "Methods and Algorithms for Fuzzy Cognitive Map-based Modeling." In Fuzzy Cognitive Maps for Applied Sciences and Engineering. Berlin Heidelberg: Springer-Verlag.

Papageorgiou, E. I., Stylios, C. D., and Groumpos, P. P. 2004. "Active Hebbian learning algorithm to train fuzzy cognitive maps." International Journal of Approximate Reasoning no. 37:219-249.

Parry, M. L. 2009. "Climate Change is a Development Issue, and Only Sustainable Development Can Confront the Challenge " Climate and Development no. 1 (1):5-9.

Parsons, K. 2003. The Science Wars. Buffalo, USA: Prometheus Books.

Paton, D. 2000. "Emergency planning: Integrating community development, community resilience and hazard mitigation." Journal of the American Society of Professional Emergency Managers no. 7:109-118.

Peirce, C. S. 1932. Collected Papers. Edited by C. Hartshorn, P. Weiss and A. Burks. Cambridge, MA: Harvard University Press.

Perrings, C. 1998. "Resilience in the Dynamics of Economy-Environment Systems." Environmental and Resource Economics no. 11 (3-4):503-520.

Perrings, C. 2006. "Resilience and sustainable development." Environment and Development Economics no. 11:417-427.

Pett, J. 2009. What if it's a big hoax and we create a better world for nothing? : USA Today.

Pimm, S. L. 1991. The balance of nature? Chicago, Illinois, USA: University of Chicago Press.

Pimm, S. L., and Lawton, J. H. 1977. "Number of trophic levels in ecological communities." Nature no. 268:329-331.

Pretty, J. 2003. "Social capital and the collective management of resources." Science no. 302:1912-1914.

Prowse, M., and Scott, L. 2008. "Assets and Adaptation: An Emerging Debate". In IDS Bulletin. Brighton, UK: Institute of Development Studies.

Putnam, R. 1994. Making Democracy Work: Civic Traditions in Modern Italy: Princeton University Press.

Quine, W. V. O. 1969. Ontological Relativity and Other Essays. New York, U. S. A. : Columbia University Press.

Ramírez, R., and Ravetz, J. 2011. "Feral Futures: Zen and Aesthetics. Futures.no. 43 (4):478-487.

Ramírez-Villegas, J., Lau, C., Köhler, A.-K., Signer, J., Jarvis, A., Arnell, N., Osborne, T., and Hooker, J. 2011. Climate analogues: finding tomorrow's agriculture today. Cali, Colombia: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Redman, C. L., and Kinzig, A. P. 2003. "Resilience of past landscapes: resilience theory, society, and the longue dureé." Conservation Ecology no. 7 (1).

Resilience Alliance. 2014. Resilience 20022014. Available from http://www.resalliance.org/576.php.

Ribot, J. C. 2009. Producing Poverty and Vulnerability in the Forest Villages of Eastern Senegal,edited by Jesse C. Ribot Prof: Association of American Geographers, 1710 16th St, NW Washington, DC 20009 USA.

Ritchey-Vance, M. 2002. "Social Capital, Sustainability, and Working Democracy: New Yardsticks for Grassroots Development." In The Earthscan Reader on NGO Management, edited by M. Edwards and A. Fowler. London: Earthscan.

Rittel, H., and Webber, M. 1973. "Dilemmas in a General Theory of Planning." Policy Sciences no. 4:155–169.

ROBIN. 2014. Role of Biodiversity in Climate Change Mitigation in the Amazon. European Commission FP7 Research Program 20142014]. Available from http://www.robinproject.info.

Robinson, J., Burch, S., Talwar, S., O'Shea, M., and Walsh, M. 2011. "Envisioning Sustainability: Recent progress in the use of participatory backcasting approaches for sustainability research." Technological Forecasting and Social Change no. 78 (5):657-768.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H., Nykvist, B., Wit, C. A. D., Hughes, T., Leeuw, S. v. d., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., and Foley, J. 2009. "Planetary boundaries:exploring the safe operating space for humanity." Ecology and Society no. 14 (2).

Rockström, J., Steffen, W., Noone, K., Persson, Ã., Chapin, F. S., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., Wit, C. A. D., Hughes, T., Leeuw, S. V. D., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., and Foley, J. A. 2009. "A Safe Operating Space for Humanity." Nature no. 461 (7263):471-475.

Rosenbrock, H. H. 1960. "An Automatic Method for Finding the Greatest or Least Value of a Function." Computer J. no. 3:175-184.

Rosenzweig, M. L. 1971. "Paradox of enrichment: destabilisation of exploitation ecosystems in ecological time." Science no. 171:385-387.

Rougé, C., Mathias, J.-D., and Deffuant, G. 2013. "Extending the viability theory framework of resilience to uncertain dynamics, and application to lake eutrophication." Ecological Indicators no. 29:420-433.

Ryan, A. 2007. A Multi-disciplinary Approach to Complex Systems Design, Department of Mathematics and Computer Science, University of Adelaide, Adelaide.

Saavadra, C., and Budd, W. W. 2009. "Climate change and environmental planning: Working to build community resilience and adaptive capacity in Washington State, USA." Habitat International no. 33 (3):246-252.

Scheffer, M. 2010. "Foreseeing Tipping Points." Nature no. 467:411-412.

Scheffer, M., Carpenter, S., Foley, J. A., Folke, C., and Walker, B. 2001. "Catastrophic shifts in ecosystems." Nature no. 413:591-596.

Scheffer, M., Westley, F., and Brock, W. 2003. "Slow Response of Societies to New Problems: Causes and Costs." Ecosystems no. 6:493-502.

Schipper, L., Liu, W., Krawanchid, D., and Chanthy, S. 2010. Review of climate change adaptation methods and tools. In MRC Technical Paper. Vientiane: Mekong River Commission.

Schön, D. 1987. Educating the Reflective Practitioner. San Francisco, USA: Jossey-Bass.

Schroeder, A., Persson, L., and de Roos, A. M. 2005. "Direct experimental evidence for alternative stable states: A review." Oikos no. 110:3-19.

Scoones, I., Chibudu, C., Chikura, S., Jeranyama, P., Machaka, D., Machanja, W., Mavedzenge, B., Mombeshora, B., Mudhara, M., Mudziwo, C., Murimbarimba, F., and Za, B. 1996. Hazards and Opportunities: Farming Livelihoods in Dryland Africa, Lessons from Zimbabwe. London, UK: Zed Books Ltd.

Sen, A. 2007. Identity and Violence: The Illusion of Destiny. New York, U. S. A. : W. W. Norton and Company.

Sherrieb, K., Norris, F. H., and Galea, S. 2010. "Measuring Capacities for Community Resilience." Social Indicators Research no. 99:227-247.

Shiva, V. 1990. "Cry foul, cry freedom." New Internationalist no. 206:20-21.

Smit, B., and Wandel, J. 2006. "Adaptaton, Adaptive Capacity and Vulnerability." Global Environmental Change no. 16 (3):282-282.

Song, H. J., Miao, C. Y., Shen, Z. Q., Roel, W., Maja, D. H., and Francky, C. 2010. "Design of fuzzy cognitive maps using neural networks for predicting chaotic time series." Neural Networks no. 23:1264-1275.

Sonnenfeld, D., and Mol, A. P. J. 2011. "Social theory and the environment in the new world (dis)order." Global Environmental Change no. 21 (3):771-775.

Stach, W., Kurgan, L. A., and W, P. 2010. "Expert-based and computational methods for developing fuzzy cognitive maps." In Fuzzy Cognitive Maps: Advances in Theories, Methodologies, Tools and Applications, edited by M. Glykas. New York: Springer.

Star, S. L., and Griesemer, J. R. 1989. "Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39." Social Studies of Science no. 19 (3):387-420.

Starr, R., Newfrock, J., and Delurey, M. 2003. Enterprise Resilience: Managing Risk in the Networked Economy. Strategy and Business.

Stern, P. C. 1992. "Psychological Dimensions of Global Environmental Change." Annual Review of Psychology no. 43:269-302.

Stockholm Resilience Centre. 2014. Complex Adaptive Systems. Stockholm University 2007a2014]. Available from http://www.stockholmresilience.org/21/research/what-is-resilience/research-background/research-framework/complex-adaptive-systems.html;jsessionid=51DD8523048732F2B85605748F56CBAD?state=viewUnsubscribe&sv.url=12.33db2ae01355ec8e8f21d35.

Stockholm Resilience Centre. 2014. Social-Ecological Systems. Stockholm University 2007b2014].

Stockholm Resilience Centre. 2014. Regime Shifts Database. Stockholm University 20142014]. Available from http://www.regimeshifts.org.

Stylios, C. D., and Groumpos, P. P. 1999. Mathematical Formulation of Fuzzy Cognitive Maps. Paper read at Proceedings of the 7th Mediterranean Conference on Control and Automation, at Haifa, Israel.

Stylios, C. D., and Groumpos, P. P. 2004. "Modeling complex systems using fuzzy cognitive maps." IEEE Transactions on Systems, Man and Cybernetcs. Part A: Systems and Humans no. 34 (1):155-162.

Swedish Government. 2002. Resilience and Sustainable Development. Stockholm: Swedish Environmental Advisory Council.

Tamvakis, P., and Xenidis, Y. 2013. "Comparative Evaluation of Resilience Quantification Methods for Infrastructure Systems." Procedia Social and Behavioural Sciences no. 74:339-348.

Tarski, A. 1969. "Truth and proof." Scientific American no. 220:63-77.

Tawileh, A., and McIntosh, S. 2008. Adaptive Enterprise Security: A Soft Systems Approach to Information Assurance Management in SMEs. Paper read at Proceedings of the United Kingdom Systems Society 12th International Conference, at Oxford.

Thiong'o, O., Ouna, T., and Radeny, M. 2012. East Africa moves towards implementation plans wih the Climate Analogues Tool. CGIAR Climate Change Agriculture and Food Security Research Program.

Thompson, I., Mackey, B., McNulty, S., Mosseler, A. 2009. Forest Resilience, Biodiversity, and Climate Change. A synthesis of the biodiversity/resilience/stability relationship in forest ecosystems. . Montreal: Secretariat of the Convention on Biological Diversity, United Nations Environment Program.

Thorn, J. 2013. Relationships between ecosystem services and processes and human wellbeing. Oxford: University of Oxford.

TRANSMANGO. 2014. Exploring the Future of European Food Systems 20142014]. Available from http://www.transmango.eu.

Twigg, J. 2007. Characteristics of a disaster-resilient community. UK Department for International Development.

Ulrich, W. 1983. Critical Heuristics of Social Planning: A New Approach to Practical Philosophy. Bern, Switzerland, and Stuttgart, Germany: Paul Haupt.

Ulrich, W. 1987. "Critical Heuristics of Social Systems Design." European Journal of Operational Research no. 31:276-283.

Ulrich, W. 1993. "Some Difficulties of Ecological Thinking, Considered From a Critical Systems Perspective: A Plea for Critical Holism." Systems Practice no. 6 (6):583-611.

UNEP-WCMC. 2014. Adaptation and Resilience Planning for Communities and Protected Area Management.

Ungar, M. 2004. "A constructionist discourse on resilience: Multiple contexts, multiple realities among at-risk children and youth." Youth and Society no. 35 (3):341–365.

UNISDR. 2005. Hyogo Framework for Action 2005-2015: building the resilience of nations and communities to disasters. In World Conference on Disaster Reduction: UNISDR.

UNISDR. 2014. Terminology: Resilience 20072014]. Available from http://www.unisdr.org/we/inform/terminology.

United Nations Environment Program. 2002. “Integrating environment and development 1972-2002.” In Global Environmental Outlook 3: Past, present and future perspectives, 2-27. London, UK: Earthscan.

United Nations Office for Disaster Risk Reduction. 2007. Hyogo Framework for Action 2005-2015: Building the resilience of nations and communities to disasters.

Vaidianu, M. N., Adamescu, M. C., Wildenberg, M., and Tetelea, C. 2014. “Understanding Public Participation and Perceptions of Stakeholders for Better Management in Danuge Delta Biosphere.” In Fuzzy Cognitive Maps For Applied Sciences and Engineering, edited by E. I. Papageorgiou. Berlin Heidelberg: Springer-Verlag.

van Coller, L. 1997. “Automated techniques for the qualitative analysis of ecological models : Continuous models.” Conservation Ecology no. 1 (1):5.

van der Leeuw, S., 2000. . 2000. “Land degradation as a socionatural process.” In The Way the Wind Blows: Climate, History, and Human Action, edited by R. J. McIntosh, J. A. Tainter and S. K. McIntosh, 357-383. New York: Columbia University Press.

van der Leeuw, S., and Aschan-Leygonie, C. 2005. “A long-term prespective on resilience in socio-natural systems.” In Micro, Meso, Macro: Addressing complex systems couplings, edited by Hans Liljenstrom and Uno Svedin. Singapore: World Scientific Publishing Co.

van Nes, E. H., and Scheffer, M. 2007. “Slow recovery from perturbations as a generic indicator of a nearby catastrophic shift.” Am Nat no. 169 (6):738-747.

Van Notten, P. W. F., Rotmans, J., Van Asselt, M. B. A., and Rothman, D. S. 2001. “An updated scenario typology.” Futures no. 35 (5):423-443.

van Vliet, M., Kok, K., and Veldkamp, T. 2010. “Linking stakeholders and modellers in scenario studies: The use of Fuzzy Cognitive Maps as a communication and learning tool.” Futures no. 42:1-14.

Varghese, G. 2010. Exploring flood prone communities in Indian slums: A strength-based perspective. School of Geography and the Environment, University of Oxford, Oxford.

Vermuelen, S., Dossou, K., Mcqueen, D., Walunbengo, D., and Nangoma, E. 2008. Springing back: climate resilience at Africa’s grassroots. In Sustainable Development Opinion Papers. London, UK: IIED.

Vickers, G. 1965. The Art of Judgement. London, UK: Chapman and Hall.

Vugrin, E. D., Camphouse, R. C., and Sunderland, D. 2009. Quantitative Resilience Analysis Through Control Design. USA: Department of Energy, United States of America.

Walker, B., Holling, C. S., Carpenter, S. R., and Kinzig, A. 2004. “Resilience, adaptability and transformability in social–ecological systems.” Ecology and Society no. 9 (2).

Walker, B. H., Gunderson, L. H., Kinzig, A. P., Folke, C., Carpenter, S. R., and Schultz, L. 2006. "A handful of heuristics and some propositions for understanding resilience in social-ecological systems. ." Ecology and Society no. 11 (1).

Walker, B. H., and Salt, D. 2006. Resilience Thinking: Sustaining Ecosystems and People in a Changing World. Washington DC, USA: Island Press.

Walker, J., and Cooper, M. 2011. "Genealogies of resilience: From systems ecology to the political economy of crisis adaptation." Security Dialogue no. 42 (2):143-160.

Wegner, L., and Zwart, G. 2011. Who Will Feed the World: The production challenge. Oxford, UK: OXFAM.

Westley, F. 2002. "The devil in the dynamics: adaptive management on the front lines." In Panarchy: Understanding Transformations in Human and Natural Systems, edited by L. H. Gunderson and C. S. Holling, 333-360. Washington DC, USA: Island Press.

Westman, W. E. 1978. "Measuring the inertia and resilience of ecosystems." Bioscience no. 28:705-710.

White, L., and Taket, A. 1994. "The death of the expert." Journal of the Operational Research Society no. 45:733-748.

White, L., and Taket, A. 1997. "Critiquing Multimethodology as Metamethodology: Working Towards Pragmatic Pluralism." In Multimethodology: The Theory and Practice of Combining Management Science Methodologies, edited by J. Mingers and A. Gill. Chichester, UK: Wiley.

White, R. 2010. Adaptation of Food Systems. In Climate Week. Environmental Change Institute, University of Oxford, UK.

Wilby, R. L., Troni, J., Biot, Y., Tedd, L., Hewitson, B. C., Smith, D. M., and Sutton, R. T. 2009. "A review of climate risk information for adaptation and development planning." International Journal of Climatology no. 29 (9):1193-1215. doi: 10.1002/joc.1839.

Wildavsky, A. 1988. Searching for Safety: Transaction Publishing.

Wildavsky, A. 1995. But Is It True? Cambridge, MA, USA: Harvard University Press.

Wildenberg, M., Bachhofer, M., Isak, K. G. Q., and Skov, F. 2014. "Use and Evaluation of FCM as a Tool for Long Term Socio-Ecological Research." In Fuzzy Cognitive Maps for Applied Sciences and Engineering. Berlin Heidelberg: Springer-Verlag.

Wilkinson, A., and Eidinow, E. 2008. "Evolving practices in environmental scenarios: a new scenario typology." Environmental Research Letters no. 3. doi: 10.1088/1748-9326/3/4/045017.

Willetts, J., and Crawford, P. 2007. "The most significant lessons about the most significant change technique." Development in Practice no. 17 (3):367-379.

Windle, G., Bennett, K. M., and Noyes, J. 2011. "A methodological review of resilience measurement scales." Health and Quality of Life Outcomes no. 9 (8).

Wolter, K., Avritzer, A., Vieira, M., and Moorsel, A. v. 2012. Resilience Assessment and Evaluation of Computing Systems. Berlin Heidelberg: Springer-Verlag.

World Bank. 2011. Social Resilience and Climate Change: Operational Tool Kit. Washington DC: World Bank.

Wright, S. 1921. "Correlation and causation." Journal of Agricultural Research no. 20:557-585.

Yazdani, A., Otoo, R. A., and Jeffrey, P. 2011. "Resilience enhacing expansion strategies for water distribution systems: A network theory approach." Environmental Modelling and Software no. 26 (12):1574-1582.

Young, O. R., Berkhout, F., Gallopin, G. C., Janssen, M. A., Ostrom, E., and van der Leeuw, S. 2006. "The globalization of socio-ecological systems: An agenda for scientific research." Global Environmental Change no. 16 (3):304-316. doi: http://dx.doi.org/10.1016/j.gloenvcha.2006.03.004.