[Email received 6/28/20 from Mary Repar, repar2014@gmail.com]

Dear Connie,
I am sending in my comments a bit piecemeal. This comment goes with my written comments on RESILIENCE for the 2020 Draft MP. There are two attachments and the hyperlink in this e-mail. If there are any questions, please don't hesitate to contact me. Thank you.

Mary Repar/28 June 2020

https://www.stockholmresilience.org/

ASSESSING RESILIENCE IN SOCIAL-ECOLOGICAL SYSTEMS

A WORKBOOK FOR SCIENTISTS

Version 1.1

DRAFT FOR TESTING AND EVALUATION

ResilienceAlliance

June 2007

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I. INTRODUCTION

This workbook is structured to help guide a process of inquiry and action for those who are interested in applying the concept of resilience to complex resource problems in a region. It is intended to help policy makers, managers, users, and other stakeholders who would like to know if existing policies, or proposed new policies, are likely to achieve their stated aims (which may include some version of high but sustainable yield). What sorts of things might get in the way and lead to unexpected and undesired outcomes? Where theu exist, are the current strategic and operational plans for the region (explicit or implicit) robust to future uncertainties?

The answers to these questions require an assessment of the resilience of the system. That is, how does a system respond to management interventions, climate and other external drivers and shocks? A resilience approach to resource governance and management is in contrast to the conventional top-down, efficiency-focused, optimal state approach, offered as a normative approach by many researchers and policy advisers. A resilience approach has guided the development of this work-in-progress procedure for assessing resilience in social-ecological systems (SESs).

The development of a "resilience workbook" arose from requests to the Resilience Alliance for advice and assistance in how to assess the resilience of some particular region. The resulting workbook has taken two forms, with others pending:

i) This version - a fairly concise procedure, in the form a **workbook for scientists**, that has emerged from case-study comparisons of regional SESs in the Resilience Alliance (Walker et al 2006), building on and modifying an initial suggested framework (Walker et al 2002). It is intended as a guide for those familiar with the basic concepts of resilience and systems dynamics.

ii) A more comprehensive effort to develop a **workbook for practitioners** - people who make strategic decisions about resource policies and management. The practitioners' workbook assumes no prior scientific knowledge of resilience concepts.

The two versions are complementary and are being developed in parallel. In addition, there are efforts underway to develop more targeted versions. One of the first will be a coral reefs resilience workbook, under development in the James Cook University coral reefs group.

TERMINOLOGY – A short, introductory glossary

Because a resilience assessment of a SES must involve both biophysical and social scientists it is inevitable that issues of terminology will arise. To help reduce confusion a start on a glossary is presented here.

State variable. The systems science use of state variable, meaning the variables that define the state of the system (for an agricultural SES they could be land, crops, livestock, farmers, roads). It does not mean a “state” in the political sense

Regime, and regime-shift. Used in the sense of system dynamics (Scheffer and Carpenter (2003), A regime is the set of states that define a domain of attraction. In a regime the system has the same essential structure, function, feedbacks and, therefore, identity (Walker et al 2004). A regime shift occurs when a system crosses a threshold into an alternate domain of attraction. “Regime” here does not mean a political regime, though there may well be occasions when the two meanings are the same.

“Desirable” vs. “Undesirable” regimes. An awkward term that often raises queries – but so far nothing better has been offered. It means the way society (in general, or a particular segment) regards the flows of goods and services from one regime of a system in contrast to an alternative regime. One segment of society may regard a particular regime as desirable while another may not.

“Scenario”. A scenario is not a prediction of the future. It is a possible, plausible future that might arise under certain circumstances. A set of scenarios that bracket the range of possible futures is a useful tool for examining the kinds of processes and dynamics that could lead to a SES developing along particular trajectories. [NEEDS TO BE MADE COMPATIBLE WITH THE MEA USAGE]

WORKBOOK STRUCTURE

The workbook has three remaining sections. The first (Section II) is an outline of the activities for assessing resilience, which are structured as key guiding questions. How to answer the questions is then addressed in the following two sections. Section III presents a set of activities and questions that will lead to an assessment of resilience in the system. The final section (IV) aims to develop a prioritised set of interventions for managing and building resilience. As you work through Sections III and IV the necessary actions and questions (summarised in the tables in Section II) are presented in italics, to assist in identifying what needs to be done.

It is important to stress at the outset that the process needs to be iterative. The steps in the assessment are not self-contained and independent, and though it is necessary to start at the beginning it helps to move back and forth between them and not expect to 'finish' each one before moving on to the next.

II. Outline of the Process – Key Questions

Table 1 presents the essential questions that constitute the assessment procedure that is detailed in Section III. Table 2 (a summary of the procedure described in Section IV) lists the steps for prioritizing management interventions.

TABLE 1: Summary questions and activities that guide resilience assessment.

1. DEFINING AND UNDERSTANDING THE SYSTEM
1.1 Resilience of what? What are the big issues? Can they be considered collectively (preferable), or do they need to be dealt with separately? What are the "variables of concern"? What is it that the stakeholders (from all scales) are concerned about and wish to maintain? Identify, and approximately demarcate the boundaries of, the scales you need to consider. Considering the ecosystem goods and services that support the main resource uses and also the non-marketed ecosystem goods and services, relatively, how important are these biophysical variables? Which of them are most significant and need to be included in the assessment? From the perspective of the key groups of people in the region (i.e., with respect to policy, management, and use of natural resources), what conflicts, issues, and challenges do they face? And what conflicts, issues, opportunities, and challenges might future generations face? Which of these challenges, conflicts, opportunities, and issues most need to be included in the analysis?
1.2 Resilience to what? What are the system drivers and disturbances? What are the trends in the major resources (soils, water, biota), and the major resource uses? What important ecological and social changes are currently taking place? How have they changed over time - gradual ramp up, slow decline, rapid jump, collapse, oscillation? What are the characteristic disturbances, in both the social and ecological domains, at each relevant scale? Are there changes in the patterns of these disturbances – in frequencies or intensities? Are there novel kinds of disturbances emerging? Are there attempts by managers to control or modify these disturbance events?

Develop a historical profile of the system. Identify the times/periods of major events that changed the system. It is useful to do this at each scale of analysis (the focal scale, below and above), and identify cross-scale connections – how events at one scale either caused or resulted from events at another scale.

How has the system been modified to alter the flows of a) goods, and b) ecosystem services?

Considering these modifications, re-visit the "big issues". Do they need to be changed?

Using the insights gained from this historical profile, try to identify underlying controlling variables (often ones that have been changing slowly) that caused changes in the natural system, the people, and in the interventions that people made.

1.3 People and governance

Key Players. Identify individuals or organisations who have key leadership roles

Where does the real power lie? Who has the power to influence the system, directly through changing policies, or indirectly through voting, lobbying, advertising, or funding those with direct power?

Governance. At each scale of governance: What are the property rights? How much public land (or water) and private land is there, and are there common property resources? Are property rights, and access rights, clear and agreed by all? How do the different kinds of tenure conflict with or complement each other, and is their juxtaposition a factor in this?

Who controls resource use and regulations at each relevant scale? What are the relationships between the control agencies? How much overlap is there?

What other formal bodies exist in regard to resource use (e.g., advisory)?

What other informal institutions are important in regard to resource use (e.g., lobby groups, informal associations or groups)? How flexible or variable are they? How effective are social networks and what role are they playing (or could they play) in learning and changes in resource use and management?

Are there key policies, laws or regulations governing resources use that enhance or constrain flexibility to manage resources and issues that arise?

Are there cross-scale influences (such as interactions of national land tenure with traditional local tenure)?

2. ASSESSING RESILIENCE

2.1 Developing conceptual models

What mental models of ecosystem dynamics exist, for different user groups, and how do they differ between user groups, and between users and researchers? How do they differ in regard to the responses of ecosystems to various kinds and levels of use?

How do the mental models of social 'values' and benefits derived from ecosystem use differ? Are there clearly different attitudes to ecosystem use and the value of ecosystems to society?

Does the system (at the focal scale of interest) appear to be in a particular phase of the adaptive cycle? If so, how long has it been in that phase, and does it appear to be approaching a phase change? Refer back to the historical profile and examine it for a likely pattern involving the current system state.

Can you identify the main scales above and below the focal scale? Considering the issues you identified earlier, what are the most significant cross-scale influences (effects) that have a bearing on the dynamics of the system at the focal scale?

Using the mental models that stakeholders (including scientists) have of ecosystem dynamics, develop a conceptual and/or state-and-transition model of how the system behaves. Consider the following set of questions to guide model development:

What does the system consist of? Based on what's been learned about the variables of concern, the controlling variables that determine their dynamics, and the drivers and disturbances, start describing the system in terms of a box-and-arrow diagram. This diagram describes the structure (state) of the system at any particular time.

For a state-and-transition model, What are the possible states (structures) the system can be in? What transitions between the states are possible? Can you identify possible future trajectories (development pathways) of the SES? For these trajectories, can you identify any different "end-states" the system could be headed for, and what the intermediate states might be? Where, along the various pathways, are there non-return points, that foreclose moving to other trajectories?

Critical assumptions: In this conceptual model try to identify, make explicit, and keep track of the assumptions that underlie the dynamics. Which assumptions need to be tested, either in models or through management?

2.2 Alternate system regimes

Can you now develop a conceptual model of possible regime shifts, and of thresholds? Can you posit alternate basins of attraction, at various scales, in the ecological, economic and social domains?

Which drivers are pushing the system towards thresholds, and which disturbances (shocks) are likely to cause the system to cross a threshold?

What are the likely consequences for the system if these thresholds are crossed? Is it possible to restore the system to its original state once these thresholds have been crossed? Are there alternate regimes (basins of attraction), either realized or potential, and can the system flip into an alternate undesirable regime?

Is the system already in an undesirable basin? If so, is it possible (technically/economically/legally/socially, etc.) to navigate out of that basin?

Likely pathways into the future (scenario analysis). Identify 2 or 3 possible pathways into the future, in terms of land use, livelihoods, population numbers and distribution, climate, economic conditions, etc., that bracket the range of possible futures. (NOTE: A scenario is not a prediction. It is a possible future)

Considering the possible state changes suggested by the state and transition 'model', are there any likely transitions that indicate irreversible, or hysteretic, changes? What are the controlling variables in the system on which these thresholds might occur? Consider also possible future changes in flows of desired ecosystem goods and services and desired social conditions in identifying these controlling (slow) variables.

What kinds of economic and social tipping points (e.g., in social attitudes that might lead to changes in regulations) are likely or possible in the transitions between states?

Feedback changes: What feedbacks are evident in the pattern of system dynamics, in regard to the ways in which the amounts of these key slow system variables are regulated? Consider both negative and possible positive feedbacks. In particular, what feedbacks occur between the ecological and social domains?

From conceptual to quantitative models: Try to determine where the thresholds are, and what determines their positions on the controlling variables (a quantitative model may be helpful in determining threshold positions but quantitative assessment of thresholds is technically challenging).

2.3 Likely interactions among thresholds

Considering each of the derived future pathways (scenarios) in turn, examine the effects of likely "shocks", including normal variation in environmental or social conditions, on the dynamics of the system in relation to each threshold, and assess the relative likelihoods that the thresholds will be crossed. Using the Fig 4 type of template, develop possible/likely sequences (cascades) of thresholds being crossed.

2.4 Cross-examination of models with attributes

Response diversity. Are there key functional groups (ecological or social) that are represented by only one or two different species or members? Has response diversity changed? Increases in efficiency of production (eg, removal of apparent redundancy) can reduce response diversity and decrease resilience. Has this kind of efficiency been increasing? Is it a goal of management?

Feedback changes. Thinking about feedbacks that control key 'slow' variables, what has changed, is changing, or is likely to change? Are feedbacks in the system getting weakened or delayed? Is the gap between an individual's or an organisation's actions, and their knowledge of the consequences of those actions, widening?

What are the current directions and rates of change of important slow variables? What could alter this? Which variables influence it?

Is the system becoming more inter-connected? How does this aspect relate to identified processes and feedbacks?

Adaptability
Governance. How important are elements of the governance system (described in section 1.3.2) in influencing the capacity of the social domain to respond to and manage the resource base? And how important are they in the resilience of the governance system itself?

Social capacity. This is a difficult aspect to get to grips with and the following questions are

meant as guides to help identify where attributes of the social system are constraining (or facilitating) adaptability. Some may not be quantifiable but it may be possible to use a relative, or scale approach.
How capable is the community of responding to a crisis or disturbance? How long does it take society to respond? Importantly, what limits (or facilitates) this capacity? What is the status of community organisation (e.g., local stewards)? What social networks are in operation and are they dynamic, or restrictive? Are any feedbacks changing in the social networks? Is there evidence of: self-organisation and action, communication infrastructure and networks, lobby groups?

Are there mechanisms in place to develop leaders and leadership skills? What is happening to trust in the system – within social groups, and between social groups?

Learning. How strong is learning in the system and how does it occur? Is it an ongoing process? What limits it? Are reservoirs of knowledge and information formalized or transient? Is experimentation being encouraged or dampened? What kinds of encouragement (e.g., subsidies) is in place in regard to either promoting novelty or inducing people to keep on with the same practices? Is innovation evident? What are the sources/evidence of new products, crop types, markets, institutions?

What particular aspects of the social system are critical in determining social capacity in this system?

Changes in capitals. Relatively, what kinds of capitals (natural, built, human, social, financial) are mostly acting as limiting factors in determining adaptability? Which aspects of these capitals are the most important?

2.5 Cycles of change and cross-scale interactions

What phases of the adaptive cycle does the system, at each of the scales, appear to be in? What are the implications of this for the dynamics and likely future changes in the system at each scale?

What are the major influences from the scales above, and are they constraining or facilitating changes at the focal scale?

Are there particular aspects of the spatial pattern and/or inter-connections of the sub-divisions at any scale that are important in their dynamics and/or the ways they are used? How do the kinds and levels of connectivity at scales below the focal scale influence its adaptability and capacity to respond?

3. IMPLICATIONS FOR MANAGEMENT INTERVENTIONS

List the implications of the assessment for management (but don't try to provide solutions yet).

4. SYNTHESIS

Revisit the set of models developed earlier and modify and combine them to include what has

emerged in the analysis. Two key inputs include the system-specific version of Fig 4 and the lists of system attributes, at the various scales that are involved and that are significantly affecting resilience and adaptability. Identify pairs (or even triplets) of alternate basins of attraction for the system. What are the system attributes that determine the dynamics of the 'slow' variables, and the positions of thresholds on these variables, noting that different slow variables will be involved in controlling the different kinds of individual regime shifts (in different domains and at different scales) that might exist?

TABLE 2. Summary questions and activities to develop interventions for resilience management

1. KINDS AND SCALES OF INTERVENTIONS
Interventions can be grouped into four main types: Policy and institutions; Fiscal and monetary; Management guidelines; Education. Consider possible interventions in each type at each of the scales at which the institutions involved in making interventions operate. As you do this, think about the likely secondary effects and interactions between these interventions. The institutions involved in making interventions operate at different scales and it is helpful to consider possible interventions at these scales. *Critical Thresholds and Interventions* *Try to place the set of possible regime shifts in priority order for intervention, based on: a) How significant they would be; and b) how likely they are to happen (ie, how close to the threshold are they). Determine for each threshold, in relative terms at least, the likely consequences (costs) of crossing it and the costs and benefits of not crossing it* Develop a (small) set of critical thresholds that constitute priority attention for intervention. Referring to section 2.4, what are the determinants of each of these critical thresholds? These are the attributes that policy and management need to focus on.
2. MAPPING INTERVENTIONS TO PANARCHY BEHAVIOUR
Does resilience management call for: i) foreloop type actions (including education), ii) breaking K-phase behaviour (creating small disturbances?), iii) backloop interventions (retaining capitals, facilitating experiments and innovation)? In terms of panarchy behaviour, what cross-scale interventions are called for?
3. INTERACTIONS AND SEQUENCING
Considering the set of priority interventions identified above, what secondary effects might they have, and what interactions amongst them are likely? Are there any sequencing issues involved in implementing the interventions? Place the interventions into sequential order and examine the consequences, using the insights gained from the models and your understanding of panarchy effects.

4. ADAPTIVE MANAGEMENT
Try to define what is known and what is not known about management issues. Make explicit the assumptions underlying management. Design an adaptive management program, as an integral part of the planned interventions, to test these assumptions. It will likely be necessary to test the form and positions of identified thresholds for at least some of the regime shifts listed. Experiments of this kind involve costs, sometimes in the form of foregone profits where reduced levels of use are one of the 'treatments'.
5. IS TRANSFORMATION CALLED FOR?
Has the option for resolving problems through adaptation gone? If there is little chance that an acceptable outcome can be achieved through managing the thresholds in the system then intervention must focus on how to re-define the system; how to become a different kind of system.

We repeat that, in each application of the procedure we have found it helpful, if not necessary, to move forwards and back again, and not get bogged down on refining (for example) the "resilience of what". Thinking about resilience "to what", and conceptual models, helps to define the resilience of what. If you're not sure what to do next in the section on alternate regimes, move to considering cycles of change and use that to help reconsider alternate regimes. And so on.

III. RESILIENCE ASSESSMENT

What are the big issues?

Assessing resilience in social-ecological systems requires engagement of a knowledgeable group, including, practitioners and all other stakeholder groups, to identify issues and problems. An assessment should determine what is important and integrate accumulated experience and knowledge (see for example Brown et al, 2001, and also the "Practitioner" version of the workbook). A social-ecological inventory (Olsson et al, ref) is another way to elicit the main issues that need to be addressed.

Clarifying and identifying the issues is an important part of defining the system. It is impossible (and counter productive) to be all-inclusive. Focussing on the big issues identifies the system variables that need to be included as descriptors of the system – thus defining the system state space. It has been our experience that getting agreement on what the system consists of is a difficult task and can take considerable time and discussion.

Should the issues be assessed separately, or together?
Feedback from practitioners in the development of this workbook indicates that the assessment procedure needs to be issues-based. Once they've been identified, in order to avoid coming up with partial solutions it is best to treat the issues collectively. In some cases, however, where the issues concerned are substantially different and involve different time and space scales, it is pragmatic and easier for stakeholders who are involved to initially consider them separately. In such cases, it is appropriate to work through steps 1, 2 and 3 (below), for each issue in turn. In most cases, however, the issues are too closely entwined to treat separately.

Identifying the big, "important" issues is clearly a subjective process and the identified set will differ for different segments of society (stakeholder groups). It is therefore essential for the validity of the assessment, and its eventual acceptance by society, to include all stakeholder interests. This places an emphasis on considering stakeholders at different scales, including those at larger scales (often outside the focal scale of interest) who may not normally be considered and who may not have any power. Time spent initially on stakeholder analysis, and identifying stakeholder concerns, will avoid subsequent development of partial, inadequate assessments.

Having emphasized the importance of this first stakeholder analysis step, experience so far does suggest that in SES regions where the need for a resilience assessment has arisen, there are usually a limited set of over-arching big issues that require attention.

1. DEFINING AND UNDERSTANDING THE SYSTEM

The preceding discussion highlights that in any SES there are multiple perspectives each with a particular focus. The scientific focus is only one of these. None of them captures "the truth" about the system. "Mental models" are fundamental to any participatory approach, and elucidating people's (stakeholder group) mental models, as best as possible, helps to achieve a more comprehensive assessment.

1.1 Resilience *of* What?

For those new to the concept of resilience (and for those who need reminding) Box 1 presents a short summary of what we mean by "resilience".

BOX 1
WHAT IS RESILIENCE? - BASIC CONCEPTS

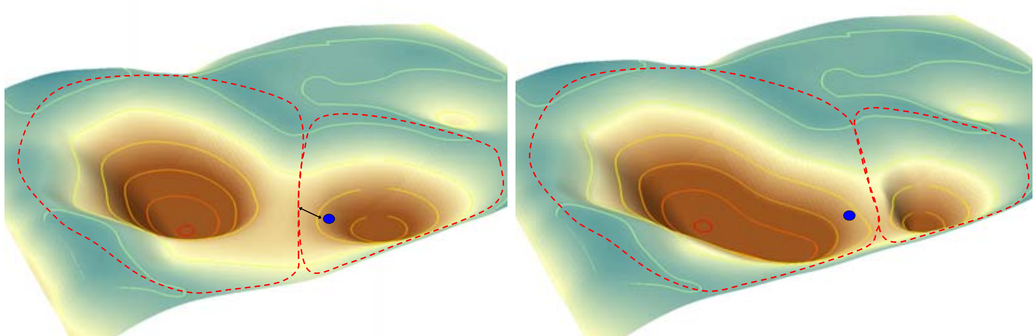
The essential feature of a social-ecological system is a multi-scale pattern (both spatial and temporal) of resource use around which humans have organised themselves in a particular social structure (distribution of people, resource management, consumption patterns, and associated norms and rules). The aim of resilience management and governance is to keep the system within a particular configuration of states that will continue to deliver (on some societally determined time scale) desired levels of ecosystem goods and services, and to either prevent the system from moving into un-desirable configurations from which it is either difficult or impossible to recover, or move from a less desirable to a more desirable configuration. The basic concepts involve ***non-linearity, alternate regimes and thresholds.***

Because of non-linear dynamics many (most) systems can exist in what are generally called alternate stable states. The term "states" is used loosely in much systems literature, and can be confusing, so we need to define its use here. The state of a system at any time is defined by the values of variables that constitute the system. For example, if a rangeland system is defined by the amounts of grass, shrubs and livestock, then the state space is the three-dimensional space of all possible combinations of the amounts of these three variables. The dynamics of the system are reflected as its movement through this space (see Walker et al (2006) for more on basic resilience propositions). Using the metaphor of basins of attraction in a stability landscape (Walker et al 2004 -- and we stress that this only a metaphor to help us visualise alternate system regimes), the SES can exist in one or more system configurations. Some configurations are desirable from a human perspective, and others are undesirable. Each configuration is actually a set of system states that has the same essential structure and function - and such a configuration (same structure and function) is termed a system "regime". As biophysical and social attributes of the system change, the positions of the attractors move around, and the various basins of attraction get smaller and larger, or appear and disappear.

Alternate regimes are separated by thresholds that are marked by levels of controlling (often slowly changing) variables where there is a change in feedbacks. It is the changed feedbacks that lead to the changes in function and therefore structure.

Resilience is a measure of the topology of such basins (alternate regimes). Following the above descriptions of system states and regimes, we define resilience as the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks (Holling 1973, Walker et al 2004).

The first aim in assessing resilience in SES's is to identify the axes (dimensions) of the stability landscape that reflect changes in key variables of concern. What are the essential components in the system that determine the flows of goods and services that people really care about? With the dimensions agreed and defined, the aim is then to identify the attributes of the system that determine the sizes and shapes of the basins (positions of thresholds), the capacity to influence the trajectory of the system in the stability landscape, and the capacity of external perturbations to shift that state.



Three-dimensional stability landscape with two basins of attraction showing the current position of the system (the 'ball') and how it can shift regimes as the stability landscape changes

The analysis of the significant issues (e.g., loss of coastal wetlands, declining fish stocks, changing markets) provides the best basis for defining the system and identifying the "state space" of the system. *What are the "variables of concern"? What is it that the stakeholders (from all scales) are concerned about and wish to maintain?* Before proceeding too far in doing this, there is a need to consider the relevant scales that need to be addressed.

Whatever the main scale of interest might be, you cannot understand (or manage) the system by examining it at only that scale. The dynamics of the system at that scale are influenced by changes at scales above and below. *Identify, and approximately demarcate the boundaries of the scales you need to consider.* For example, a region such as a catchment or an administrative region might be made up of different farms, or ecosystem types, and in turn it may be one of several such regions in a river basin, or a State. You may be primarily interested in a marine park that is situated in a fishing zone, or perhaps in a larger marine reserve system. You may be interested primarily in a broader system (like the Great Barrier Reef in Australia), in which case the scales above include the surrounding oceans and the adjacent land with its various land uses. The relevant scales that are needed are identified either by their influences on the focal scale, or the influence of the focal scale on them.

Again, don't get bogged down on this. Move on, and come back to refine it as you get further into the analysis.

The variables of concern (emerging from the big issues) tend to fall into three classes: i) ecosystem goods and services that are directly used, ii) non-marketed ecosystem goods and services, iii) the 'state' of people (community/society).

i) The ecosystem goods and services that are directly used – those that support the main (natural) resource uses - commonly fall into categories such as:

- economic (commercial crops, timber, tourism, etc.)
- subsistence
- recreational/aesthetic
- cultural (tradition, ritual)
- conservation

(See Hein et al 2006, and Abel et al, on: http://www.ecosystemservicesproject.org/html/publications/docs/Natural_Assets_LR.pdf, for more on this)

ii) Non-marketed ecosystem goods and (especially) services, in terms of benefits to humans, inside and outside the region. For example, clean water and soil fertility maintenance. Services like these are often initially unrecognised by stakeholders, but they can be of great importance.

A useful framework for considering the set of ecosystem services, provided by Hein et al (2006), is given in Figure 1. We would modify their "regulation" services to read "regulation and re-generation" services, to emphasize the importance of soil fertility maintenance, water filtration, etc. The focus here is on identifying the main variables of concern, so their step 4 (a contentious and difficult part) is not needed - at least at this stage. When we come to trying to determine the cost of a regime shift, quantifying the value of this set of services for the system when it is in each of the alternate regimes, is indeed, a difficult task.

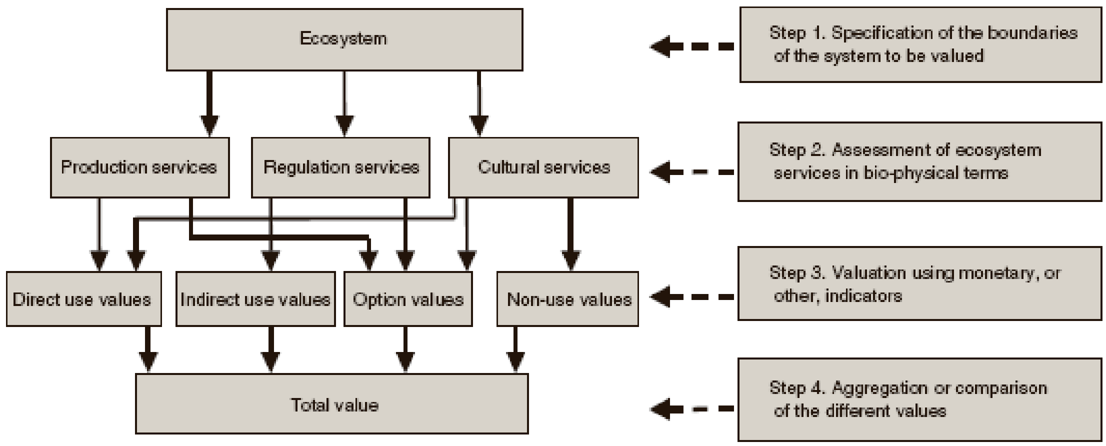


Figure 1. From Hein et al (2006) – A framework for considering the supply of ecosystem services.

Considering i) and ii) together, relatively, how important are these biophysical variables? Which of them are most significant and need to be included in the assessment? You need to limit the degree of disaggregation in defining these variables. For example, though individual stakeholders may identify particular crops as important (wheat, barley, rye), is this level of detail really necessary, or is it actually cereal output, or aggregate crop production, that is important?

iii) In some cases the condition ("state") of people (the community, society) is a major variable of concern. As an example, in some rural areas land degradation and declining terms of trade lead to reduction in numbers of farmers. As some farmers leave others take over their properties to make their own enterprises more viable. As this proceeds, there are insufficient children to warrant a school in the village. When the school closes and the teachers leave, the local medical practitioner leaves, and so on. Community viability is a variable of concern in such an SES, influenced by what is happening in the biophysical part of the system.

We can now rethink who the key groups in the region are (ie with respect to policy, management and use of natural resources). *From the perspective of each key group, what conflicts, issues, and challenges do they face? And what conflicts, issues, opportunities, and challenges might future generations face?*

Which of these challenges, conflicts, opportunities, and issues most need to be included in the analysis?

Considering each of the big issues in terms of classes i) to iii) above enables you to define the system and the "resilience of what". But remember - the procedure needs to be iterative. If you get bogged down, move to the next step, or even jump ahead (perhaps try the historical profile), and then come back to this one. The smaller the state space of the system the more focussed the assessment, the more valuable the insights, and the more likely it will be embraced.

1.2. Resilience *to* What? - Drivers, disturbances and likely future scenarios

A regime shift generally occurs as a result of two processes (see Box 1): i) The system gets closer to a threshold, either because the threshold moves closer to it (loss of resilience – the basin of attraction is shrinking), or as a result of system drivers that move it (the state of the system) along the controlling (slow) variable on which the threshold exists. ii) A "shock" to the system pushes it across the threshold. The shock can be just the normal variation in the system's disturbance regime once the distance of state of the system from the threshold is within the normal level of variance. We therefore need to know about the drivers of the system, and the kinds of possible shocks to which it might be subjected.

An analysis of system resilience needs to bracket the range of future stresses and shocks, and identify a few broad (classes of) acceptable and unwanted but plausible trajectories. The trajectories a system might take can then (in the following step) be analysed in terms of possible thresholds between alternate system regimes. A process involving only scientists will not produce the insights that come from involving other stakeholders and wherever possible participatory workshops should be run before any resilience analysis is undertaken. Stakeholder assessment and engagement is dealt with in the "Practitioner Workbook". However, provided it takes into account all that is known about stakeholder trends, differences and aspirations, a scientist-only assessment may nevertheless provide valuable insights into where in the SES resilience resides, and how to manage it (we return to this later).

1.2.1 Identifying system drivers and disturbances

Knowing what people are trying to achieve in the region helps to identify trends in critical controlling (often "slow") variables (like the accumulation of phosphate in lake sediments). This assessment can really only be done by the SES stakeholders (see, for example, the account of scenario analysis, Peterson et al, 2003).

What are the trends in the major resources (soils, water, biota), and the major resource uses? What important ecological and social changes are currently taking place (eg, changes in species, in land cover, land-use practices, human demography, economics)?

How have they changed over time - gradual ramp up, slow decline, rapid jump, collapse, oscillation?

Consider, in particular, changes in disturbances; *are there changes in frequency or intensity of the characteristic disturbances in the system?* Disturbances are the shocks that can push a system over a threshold on a controlling variable, so we need to know if there are changes in the levels of controlling variables (once we have identified these controlling variables) and if there are changes in the shocks the system is subjected to.
Consider drivers vs. shocks. They can sometimes be the same – like changes in climate, where a climate trend is a driver, and a shock is a particular event (drought, flood). Changes in the controlling variables are often due to changes in system drivers (e.g., demography, climate trends, new technology, external markets, etc.).

What are the characteristic disturbances, in both the social and ecological domains, at each relevant scale? Are there changes in the patterns of these disturbances? For example, are they changing in spatial scales, or temporal scales ('events' becoming more or less frequent)? Are there novel kinds of disturbances emerging? Are there attempts by managers to control or modify these disturbance events?

From studies thus far the 'shocks' to which social-ecological systems tend to be subjected, fall into the following categories:

- Physical - weather (e.g., droughts, very wet periods, hurricanes, etc.). Distinguish between trends in climate and individual weather events, earthquakes, volcanic explosions, etc.
- Biological – mainly diseases
- Economic – market shocks, trade bans, etc.
- Social – preference changes, but also population issues and labour availability
- Policy

The important and difficult thing to do here (the nub of a resilience analysis) is to identify the set of critical, controlling (slow) variables. There is no simple way to do this. We start that in earnest in Section 2 – Assessing Resilience, but it is useful at this stage to develop a historical profile of the system, detailing how it has come to be what it currently is.

1.2.2. *Develop a historical profile of the system.*

The aim here is to identify the major, controlling variables that shaped the system and that continue to shape it now. Identify the times/periods of major events that changed the system, e.g., environmental (major droughts, floods, freezes, storms, etc.), ecological (pest introductions, epidemics, etc.), economic (entry into new markets, etc.), technological (new technologies), infrastructural (roads, dams, etc.), political, and demographic. (See Figure 2 for an example from a catchment in SE Australia).

It is useful to develop historical profiles at each scale of analysis (the focal scale, as well as below and above the focal scale), and then to identify cross-scale connections – how events at one scale either caused or resulted from events at another scale.

How has the system been modified to alter the flows of a) goods, and b) ecosystem services?

Considering these modifications, re-visit the "big issues". Do they need to be changed?

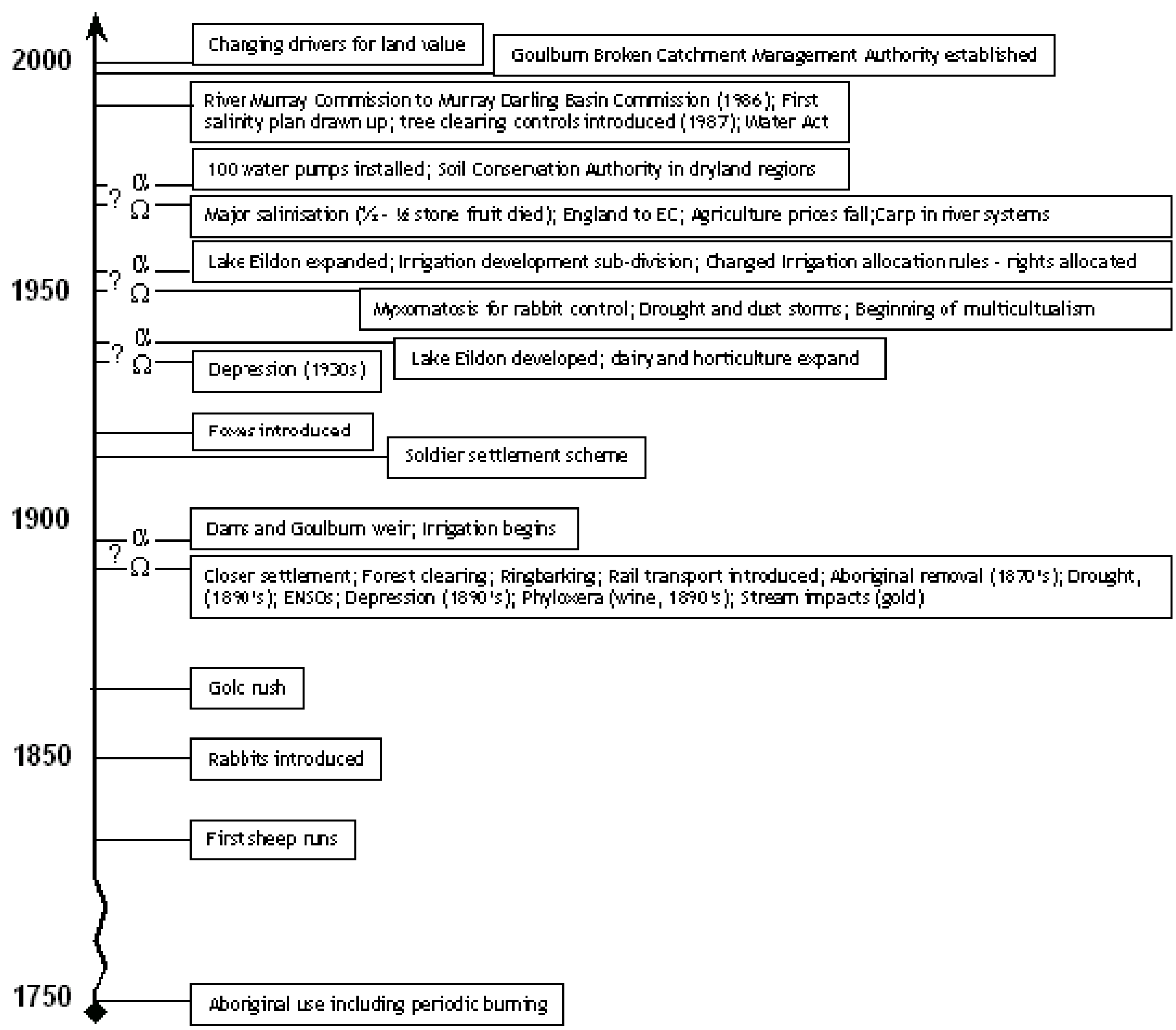


Figure 2. Historical profile of major events and developments in the Goulburn–Broken catchment. The periods with "?, α or Ω " denote times of major events or crisis, followed by reorganization. (From Walker et al 2002).

Using the insights gained from this description of the system's historical development pathway, *try to identify underlying controlling variables (often ones that have been changing slowly) that caused changes in the natural system, the people, and in the interventions that people made.* This historical assessment will be useful again later, when you come to consider adaptive cycle behaviour.

1.3 People and governance (as mediators between "of what" and "to what")

1.3.1 Key players

Earlier you identified the key stakeholder groups in the region (ie with respect to policy, management and use of natural resources). Some will reside within the region, others will not.

Can you identify individuals or organisations who have key leadership roles?

Where does the real power lie? Who has the power to influence the system, directly through changing policies, or indirectly through voting, lobbying, advertising, or funding those with direct power?

Box 1 describes what resilience is, in terms of system dimensions. "Being a resilient system" includes what can be done (or is being done) about it, and this involves two other attributes you need to assess – adaptability and transformability, described in Box 2. They are considered, specifically, later in the process, but it is important to understand at this stage what they are.

BOX 2
ADAPTABILITY AND TRANSFORMABILITY

Adaptability
Adaptability is the capacity of a SES to manage resilience in relation to alternate regimes (sometimes called adaptive capacity). It involves either or both of two abilities:
i) The ability to determine the trajectory of the system state - the position within its current basin of attraction;
ii) The ability to alter the shape of the basins, that is move the positions of thresholds or make the system more or less resistant to perturbation.
The abilities to effect both of these are determined by a combination of attributes of both the social domain and the ecosystem.

Transformability

In cases where a system is already in an undesirable regime and efforts to get it back into a desirable regime are no longer possible (or worse, make the undesirable basin larger), one option for resolving the predicament is transformation to a different kind of system - new variables, new ways of making a living, different scales - a different panarchy.

1.3.2 Governance

Governance includes all aspects of rules and regulations that determine what and how people use the resource base. There are many, and it is useful to start with what rights people have to accessing or controlling the resources – property rights. *What are the property rights? How much public land (or water) and private land is there, and are there common property resources? Are property rights, and access rights, clear and agreed by all? How do the different kinds of tenure conflict with or complement each other, and is their juxtaposition a factor in this?*

Who controls resource use and regulations at each relevant scale? What are the relationships between the control agencies (pecking order, etc.)? How much overlap is there?

What other formal bodies exist in regard to resource use (advisory, etc.)?

What other informal institutions are important in regard to resource use? E.g., lobby groups, informal associations or groups (conservation, recreational), etc. *How flexible or variable are they? How effective are social networks and what role are they playing (or could they play) in learning and changes in resource use and management?*

Are there key policies, laws or regulations governing resources use that enhance or constrain flexibility to manage resources and issues that arise?

Are there cross-scale influences (such as interactions of national land tenure with traditional local tenure)?

The information arising from this analysis will come into play in considering appropriate interventions for resilience management and governance.

2. ASSESSING RESILIENCE

2.1. Developing conceptual models of change

The purpose of these sections is to develop multiple ways of portraying the system, each of which provides insights in to how and why the system changes over time. Using knowledge of the biophysical system the information from the historical profile and the assessment of people and governance the aim is to develop system models. The models might be simple conceptual box and arrow diagrams, complex models of linked differential equations, network structure and dynamic models – whatever helps, and is available, to provide understanding of system change. To start with it is important to understand and to specify, so far as possible, the prevailing "mental models" of the various stakeholders.

2.1.1 The prevailing mental models for ecological and social-ecological dynamics.

As discussed previously (Section 1.1) resource users and managers, policy makers, scientists and other groups analyse and intervene in social-ecological systems based on their perceptions of how the system works and how it will respond to an intervention. This applies to interventions in both the ecological and social sub-systems. Given its great significance in SES dynamics, *what are predominant mental models for the system of study? How do the mental models of ecosystem dynamics differ among different user groups, and among users and researchers? Especially, how do they differ in regard to the responses of ecosystems to various kinds and levels of use?*

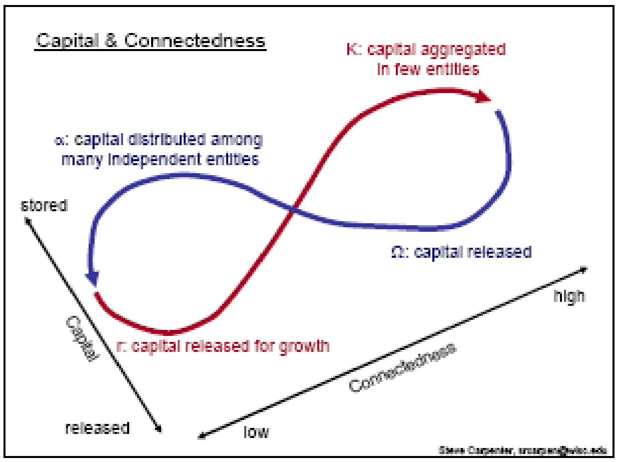
How do the mental models of social 'values' and benefits derived from ecosystem use differ? Are there clearly different attitudes to ecosystem use and the value of ecosystems to society?

2.1.2. Phases in system dynamics, critical scales and cross-scale connections

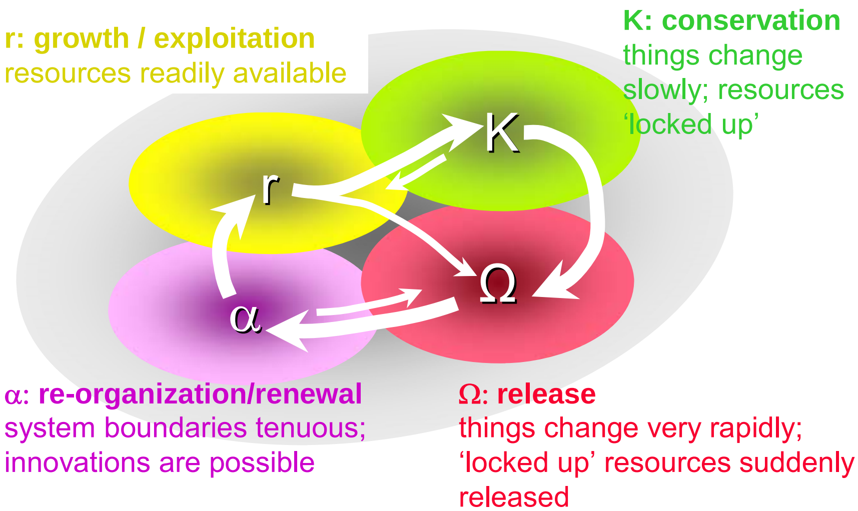
Ecosystems and social systems tend to move through different phases in their dynamics, known as adaptive cycles. Understanding which system phase can strongly influence what kinds of interventions are likely to be successful, and unsuccessful. *Does the system (at the focal scale of interest) appear to be in a particular phase of the adaptive cycle? If so, how long has it been in that phase, and does it appear to be approaching a phase change?* Refer back to the historical profile and examine it for a likely pattern involving the current system state. Box 3 describes the notion of adaptive cycles.

BOX 3
ADAPTIVE CYCLES

SESs, like all systems, are never static, and they tend to move through four, recurring phases, known as an adaptive cycle. Generally, the pattern of change is a sequence from a rapid growth phase through to a conservation phase in which resources are increasingly unavailable, locked up in existing structures, followed by a release phase that quickly moves into a phase of reorganisation, and thence into another growth phase. However, multiple possible transitions among the four phases are possible and the pattern may not reflect a cycle. The growth and conservation phases together constitute a relatively long developmental period with fairly predictable, constrained dynamics; the release and reorganisation phases constitute a rapid, chaotic period during which capitals (natural, human, social, built and financial) tend to be lost and novelty can succeed. The figures below depict the adaptive cycle in two ways – in its original form (as developed by Holling and best described in Holling and Gunderson 2002) and as a simple loop.



The adaptive cycle – in two dimensions, capital and connectedness, depicted as a fig 8 in the pattern of dynamics



The adaptive cycle, as a simple loop, showing possible changes between phases

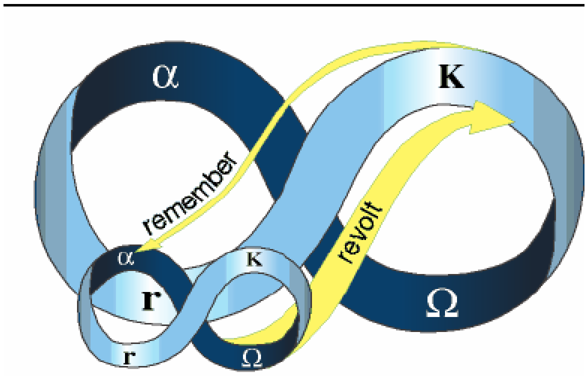
Scales and cross-scale effects

One cannot understand the dynamics of a system by examining it at only one scale. In addition to the focal scale it is necessary to understand the dynamics at scales below and above – at least one each, but most often it's necessary to look at more than one scale above. The cross-scale effects strongly influence overall system dynamics. Box 4 describes the connections between adaptive cycles at different scales – the notion of panarchy.

Can you identify the main scales above and below the focal scale? Considering the issues you identified earlier, what are the most significant cross-scale influences (effects) that have a bearing on the dynamics of the system at the focal scale?

BOX 4
MULTIPLE SCALES AND CROSS-SCALE EFFECTS – "PANARCHY"

No system can be understood or managed by focussing on it at a single scale. All systems (and SESs especially) exist and function at multiple scales of space, time and social organization, and the interactions across scales are fundamentally important in determining the dynamics of the system at any particular focal scale. This interacting set of hierarchically structured scales has been termed a "panarchy" (Gunderson and Holling 2002), illustrated below



"Panarchy" – nested adaptive cycles, with influences across scales. From above, the effects can be positive (in the form of providing "memory" and 'subsidies', but also negative (preventing actions, etc). From below, the degree to which the component (within) sub-systems are in the same phase determines the degree to which they can result in an overall focal scale change, i.e. hyper-coherence of system states or stages in the adaptive cycle at lower scales can trigger a system collapse at the focal scale ("revolt" in Gunderson and Holling 2002) .

2.1.3 A State-and-transition picture

Using the mental models that stakeholders (including scientists) have of ecosystem dynamics, the next step is to develop conceptual (and later operational) models of how the system behaves. In attempting to develop an overall model of such system change, it is often useful to begin by constructing a conceptual state-and-transition model, such as in the approach of Westoby et al (1989).

Where and how you start depends on the information available, but work through (iterate around) the following questions, in two steps:

(1) *What does the system consist of?* Based on what's been learned about the variables of concern, the controlling variables that determine their dynamics, and the drivers and disturbances, start describing the system in terms of a box-and-arrow diagram. This diagram describes the structure (state) of the system at any particular time.

(2) The state-and-transition model. *What are the possible states (structures) the system can be in? What transitions between the states are possible? Can you identify possible future trajectories (development pathways) of the SES? For these trajectories, can you identify the different "end-states" the system could be headed for, and what the intermediate states might be?* In doing this, it is necessary to think about the 'states' of the system in terms of both the ecological and social components in step (1). *Can you identify possible future trajectories (development pathways) of the SES? What are the different "end-states" the system could be headed for, and what are the intermediate states?* (Note that "states" in "end states" is used in the sense of regimes the system can be in, as defined in the opening glossary).
Where, along the various pathways, are there non-return points, that foreclose moving to other trajectories? (In other words, are there thresholds along these pathways?) In the social component of the system, thresholds are sometimes called "tipping points", and they can be behavioural (such as in voting behaviour or preferences) or more tangible (such as a tipping point in the economic welfare, like debt : income ratio, of a farm). The behavioural ones are more difficult to recognise and define, but are nevertheless equally significant in the dynamics of the SES.

Two examples of state-and-transition models are offered, to help guide thinking. Figure 3a is an example of the kind of model that helps guide thinking. It comes from the work of Mathevet et al (2006) for the reedbed system in the Camargue region of the Rhone delta. It identifies the kinds of transitions in system states that occur through purely ecological processes and those that can only occur through human interventions.

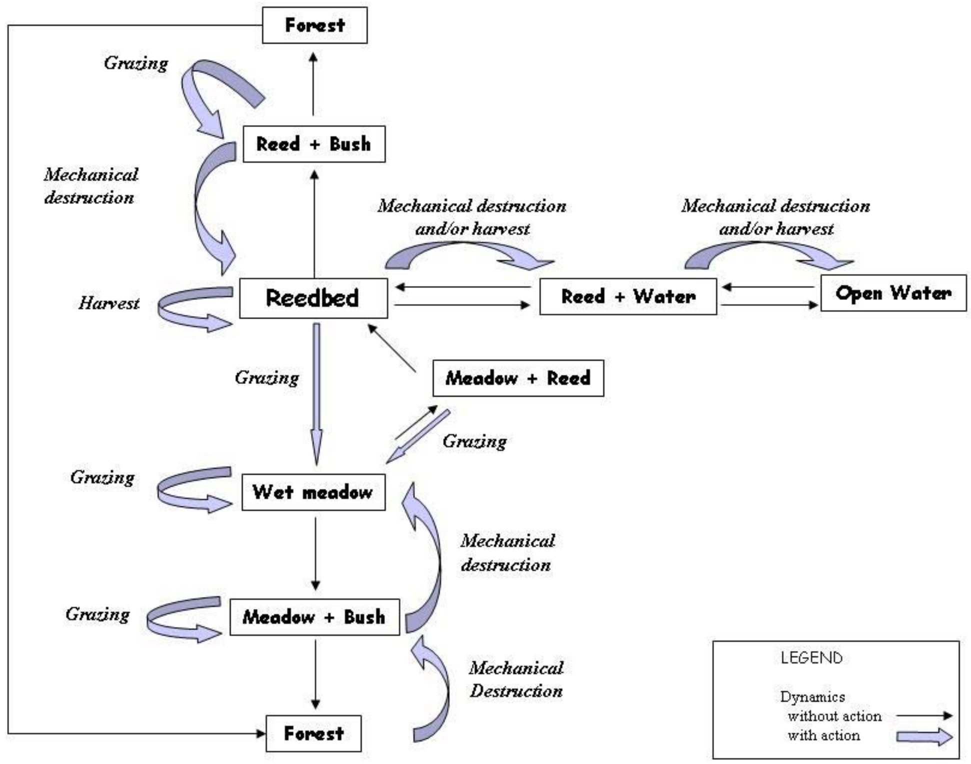


Figure 3a. State-and-Transition model of the Camargue reedbed system in the Rhone delta. Note that the boxes represent alternative states (or perhaps transitional states), and the arrows define how biotic interventions mediate the transitions among states.

As another example (Figure 3b) Ettiene (2003) describes a state-and-transition model for a sylvo-pastoral system that was subsequently used in a role-playing game to help managers decide on appropriate actions. It once again identifies different states of the system that have different consequences for people, and the natural and human drivers of the transitions between states.

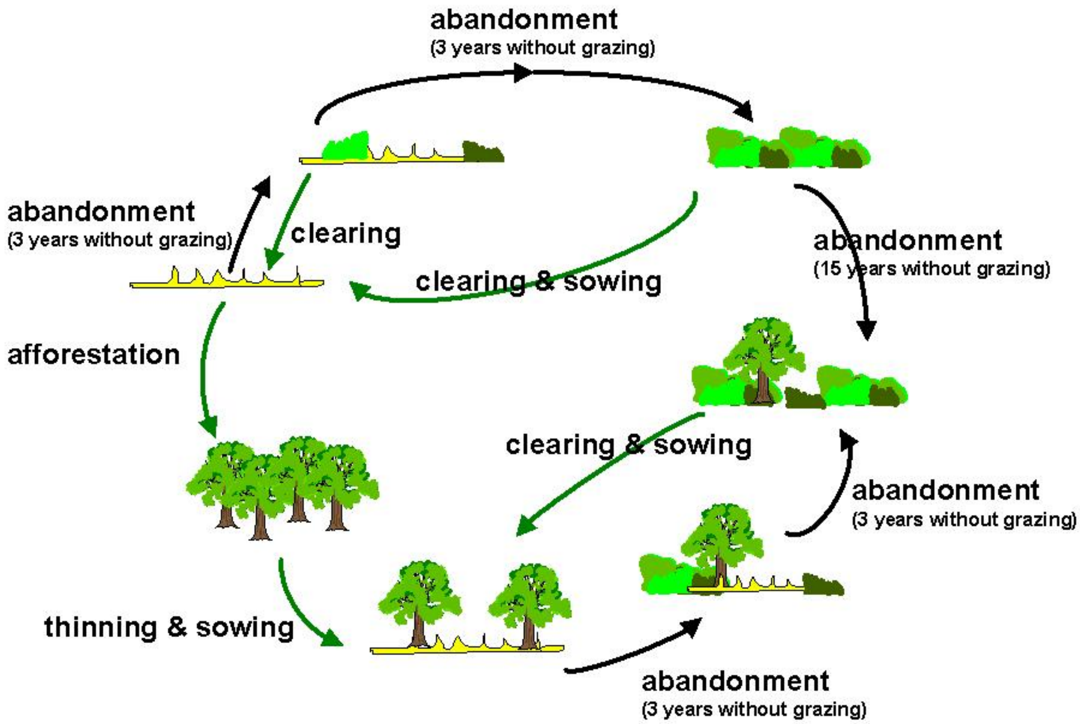


Figure 3b. A State-and-Transition model for a sylvo-pastoral system (from Etienne 2003, Figure 5).

Critical assumptions
This is a conceptual 'model' to help guide thinking, as a step towards identifying alternate regimes. In developing it, one important thing to do is to *try to identify, make explicit, and keep track of the assumptions that underlie the dynamics.* In many models implicit, unrecognised assumptions are the reason for surprises and failures in use of the model.

The list of critical assumptions needs to be carried through the next step, using the conceptual model you've arrived at for determining possible alternate regimes. *Which assumptions need to be tested, either in models or through management (see under IV. 4. Adaptive Management)?*

2.2 Alternate system regimes, controlling variables, thresholds and tipping points.

2.2.1 A conceptual model of regime shifts

Can you now develop a conceptual model of possible regime shifts, and of thresholds?

The state variables of social-ecological systems consist of two kinds - the variables of primary concern (that usually change relatively fast) that deliver value to the stakeholders, and the underlying controlling variables that determine the dynamics of the "fast" variables. Experience in several systems suggests that thresholds tend to occur along the controlling variables, and that these controlling variables are often those that change slowly. But not always. Some examples are cases of an introduced exotic pest species (rabbits in Australia) or a top predator (wolves in Yellowstone National Park) into an ecosystem. Though it takes time for the ecosystem to adjust and approach its new attractor, as soon as the new species was introduced the ecosystem dynamics and feedbacks had changed to a new regime. Controlling variables in the social domain can be either slow or fast. Ideas about controlling variables should emerge from the historical profile.

Can you posit alternate basins of attraction, at various scales, in the ecological, economic and social domains? The set of controlling variables constitutes the state space of the system in terms of its stability domains (alternate regimes), and so we need to concentrate on them. See the paper by Kinzig et al, 2006, as a guide with Figure 4 as a 'model' template for multiple interacting thresholds.

Which drivers are pushing the system towards thresholds, and which disturbances (shocks) are likely to cause the system to cross a threshold?

What are the likely consequences for the system if these thresholds are crossed? Is it possible to restore the system to its original state once these thresholds have been crossed? Asked in another way - *are there alternate regimes (basins of attraction), either realised or potential, and can the system flip into an alternate undesirable regime?* ("undesirable" can differ for different stakeholder groups, and it may be helpful here to re-visit the "resilience of what" assessment).

Is the system already in an undesirable basin? If so, is it possible (technically/economically/legally/socially, etc.) to navigate out of that basin? (If not, the only option is transformation, to some other kind of system involving new state variables and a different way of 'making a living').

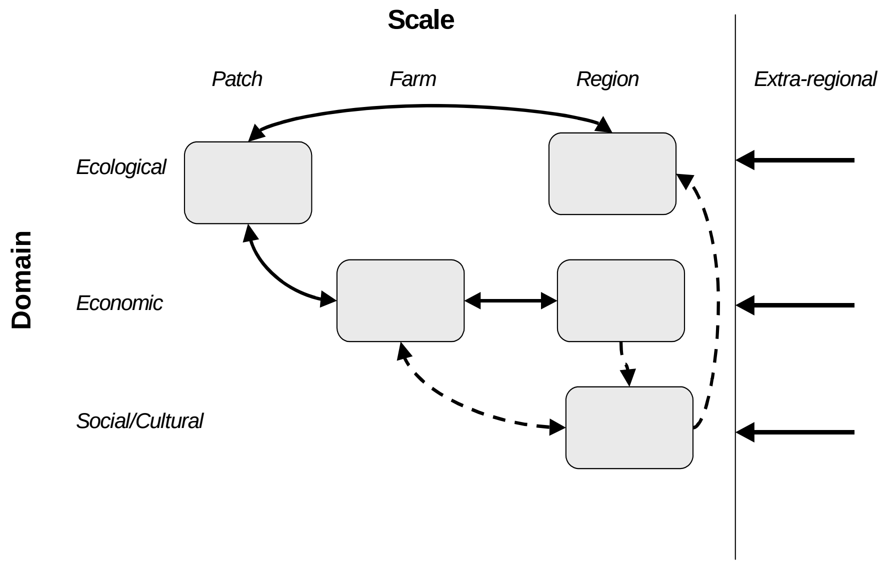


Figure 4. Multiple interacting thresholds across scales and domains (see Kinzig et al 2006). In each box, one or more thresholds were identified in each of the four regional case studies involved. Solid arrows represent threshold interactions that occurred in all four regions; for dashed arrows they occurred in at least two.

2.2.2 Likely pathways into the future (scenario development)

Considering the drivers identified earlier, and using scenario analysis ideas (see Box 5*) identify 2 or 3 possible pathways into the future, in terms of changes in land use, livelihoods, population numbers and distribution, climate, economic conditions, etc., that bracket the range of possible futures. (NOTE: A scenario is not a prediction. It is a possible future)* To do this in a useful way is not a trivial exercise. It is important, since these possible system trajectories strongly influence the likelihood of future regime shifts. For each scenario *it is important to identify the policy and management drivers of the pathway concerned.*

BOX 5

SCENARIOS OF THE FUTURE – A Tool for Envisioning Change

Scenarios are a tool for understanding regime change in social-ecological systems. Scenario planning developed as a process for addressing change in systems that are not predictable and not controllable – like social ecological systems. Change cannot be predicted accurately, and the people making decisions have only limited and narrow capabilities to control change. A scenario is a structured narrative about a possible future path of a social-ecological system. A scenario is not a forecast; instead scenarios stress the unpredictable and the uncontrollable in order to represent key uncertainties about the future of the social-ecological system. Typically, three to five scenarios are developed, bracketing the range of plausible futures. The small number of scenarios forces participants to prioritize the most critical variables. If more scenarios were used, it would be impossible for people to grasp the implications. Comparison of a few scenarios reveals drivers of change, major uncertainties, options for action, and plausible outcomes

2.2.3. Possible alternate regimes and thresholds

Considering the possible state changes suggested by the state and transition 'model', are there any likely transitions that indicate irreversible, or hysteretic, changes? Such transitions involve thresholds that demarcate alternate system regimes.
What are the controlling variables in the system on which these thresholds might occur? Consider also possible future changes in flows of desired ecosystem goods and services and desired social conditions in identifying these controlling (slow) variables.
Note, again, that in terms of the social domain of the system, some of the control variables may not be "slow", as they are in most cases in the ecological domain. In the social sciences, the term "tipping points" has been used to describe threshold phenomena. *What kinds of economic and social tipping points (for example, in social attitudes that might lead to changes in regulations) are likely or possible in the transitions between states?*

Feedback changes
What feedbacks are evident in the pattern of system dynamics, in regard to the ways in which the amounts of these key slow system variables are regulated? Consider both negative and possible positive feedbacks. In particular, *what feedbacks occur between the ecological and social domains?* Thresholds are characterised by levels on controlling variables where feedbacks change.

Having said this, there are two basic kinds of regime shifts, as indicated earlier in the examples of pests and top predators; those associated with thresholds on variables that change (often slowly), like accumulating phosphorous in the mud under a lake, and those that occur in response to the presence or absence of a variable – e.g., the top predator or introduced species. Consider the example of the introduction of rabbits to Australia. Once introduced, the system moved into a new ecological regime and started to approach the new attractor. The new regime is demonstrably different, ecologically, to the pre-rabbit regime. Hares, on the other hand, also an introduced species in Australia, did not cause a regime shift – their numbers were never destined to reach levels that could effect one.

From conceptual to quantitative models

Now comes a difficult part of the process – trying to determine where the thresholds are, and what determines their positions on the controlling variables. In a few cases it will be known; for example, the threshold for a regime shift in salinity due to rising water tables is c.2m below the surface of the soil, because (depending on soil type) that is the depth where capillary action can bring water to the surface; it is the point where there is a marked change in feedbacks in the system. The threshold effect at about this depth has been observed many times. In many other cases, however, the threshold point is not clear.

Assuming a threshold does exist, it is necessary to estimate the probability of exceeding it within some time frame. Without knowing the exact position of the threshold, if the probability of exceeding it can nevertheless be assessed then this probability can be used, instead, for determining management priorities.

Development of a quantitative model with measurements of the variables and parameters to identify the position of a threshold is a possibility, but likely to be a time-demanding and probably expensive process. Quantitative assessment of thresholds is technically challenging and is currently an active area of research (Carpenter 2003, see pages 146 - 156). If you lack extensive data about your thresholds, it is probably best to consider several different models with diverse, plausible assumptions about the thresholds.

2.3 Likely interactions among thresholds

Considering each of the derived future pathways (scenarios) in turn, examine the effects of likely (possible) “shocks”, including normal variation in environmental or social conditions, on the dynamics of the system in relation to each threshold, and assess the relative likelihoods that the thresholds will be crossed. Using the Figure 4 type of template (and it may well need additional ‘boxes’ to encompass the thresholds) develop possible / likely sequences (cascades) of thresholds being crossed. There may also be more than one threshold in a box. For example, in the Australian case study on the Goulburn-Broken catchment, two local-scale ecological thresholds were identified – a water table/salinity one, and soil acidity one. Note that crossing one kind of threshold (e.g., local ecological) may either preclude another being crossed, or lead to it being crossed (e.g., farm scale economic).

On completion of this part of the assessment you will have a version of Figure 4, with probabilities of thresholds being breached, and likely sequences, for each future pathway.

2.4 Cross-examination of the conceptual model(s) with propositions on resilience and adaptability

The objective here is to try to identify the attributes of the system that determine the positions of thresholds. These system attributes, and those that determine the dynamics of the system in relation to thresholds, are the key targets for management intervention aimed at resilience. To help identify these attributes that might influence resilience and adaptability, it is useful to consider the identified thresholds and the model(s) of system dynamics alongside propositions about what determines resilience and adaptability that have emerged thus far from a range of theoretical and case studies.

2.4.1 Resilience Attributes

Resilience of systems is promoted by a high 'response' diversity. If there are key functional groups with little or no diversity within them, resilience is low. Functional groups occur in all domains: Ecological (species that perform the same function in the ecosystem but which respond differently to disturbances); agricultural (numbers of crop types, etc.); industry (sources of supplies, numbers of markets/outlets); social (demographics, ethnic groups, education backgrounds). *Are there key functional groups (ecological or social) that are represented by only one or two different species or members? Has response diversity changed? Increases in efficiency of production (eg, removal of apparent redundancy) can reduce response diversity and decrease resilience. Has this kind of efficiency been increasing? Is it a goal of management?*

Changes in the strengths, or nature, of feedbacks influences resilience. Loosening feedbacks often tends to reduce resilience. *Thinking about feedbacks that control key 'slow' variables, what has changed, is changing, or is likely to change?* [Example: the depth of the water table is a key controlling variable of salinization in many agricultural regions in the world; and the feedback from clearing deep-rooted trees in the catchment to changes in water reaching the water table is the critical feedback process involved.]

Are feedbacks in the system getting weakened or delayed? Is the gap between an individual's or an organisation's actions, and their knowledge of the consequences of those actions, widening?

What are the current directions and rates of change of important slow variables? What could alter this? Which variables influence it?

Changing spatial heterogeneity can change resilience. Very often the change has been to make landscapes more homogeneous, leading to lowered resilience.

Modularity of systems increases resilience. In systems that are fully connected disturbances are transmitted rapidly throughout the system; modularity enables some parts of a system to avoid the disturbance (e.g., a disease), and slow the rate of spread, giving time for re-organisation. Is the system becoming more interconnected? How does this aspect relate to identified processes and feedbacks?

Network structures. Randomly connected networks are less robust to failure of nodes and connections than scale-free networks; but scale-free networks are more sensitive to targeted node 'attacks'.

Panarchy (See Section 2.5 ahead, on the importance of cross-scale effects.)

Others? The attributes of a system that determine its resilience are highly context dependent. The above examples and propositions are merely to stimulate thinking about how to identify them.

2.4.2 Adaptability Attributes

The following are some of the kinds of attributes that have been identified in enhancing the capacity to manage resilience. Again, these are 'general' features, and the aim here is to use them to stimulate thinking about, and identifying, the context-dependent attributes that are influencing adaptability in regard to the regime shifts and thresholds identified in your system.

Governance. Refer back to the information developed under section 1.3.2. The kinds of institutions that are in place, and the regulations and the rules (formal and informal) that govern what is possible and that influence peoples' choices, determine the resource use patterns that emerge. Regime shifts can be facilitated or inhibited by the governance system. Traditional beliefs often reflect evolved rules that are adhered to through religious or other social mechanisms. Erosion of such mechanisms in the absence of other institutional development reflects loss of adaptive capacity. *How important are any of the above in influencing the capacity of the social domain to respond to and manage the resource base? And how important are they in the resilience of the governance system itself?* In some cases, for example, the continuation of an effective institution can be vulnerable to a change in political leadership, so the resilience of the governance system itself needs to be considered. Adaptive co-management is a mechanism that can contribute to such resilience.

Social capacity is paramount in determining adaptability, and it depends largely on leadership, trust and networks. It is a difficult aspect to get to grips with and the following questions are meant as guides to help identify where attributes of the social system are constraining (or facilitating) adaptability. Some may not be quantifiable but it may be possible to use a relative, or scale approach. *How capable is the community of responding to a crisis or disturbance? How long does it take society to respond? Importantly, what limits (or facilitates) this capacity? What is the status of community organisation (eg. local stewards)? What social networks are in operation and are they dynamic, or restrictive?* (See under resilience on strength of feedbacks); *how is this changing in the social networks?. Evidence of self organisation and action? Communication infrastructure and networks? Lobby groups?*

Leadership can be expressed as strong or weak individual leaders; or as a community-driven process involving individuals with different capacities. *Are there mechanisms in place to develop leaders and leadership skills? What is happening to trust in the system – within social groups, and between social groups?*

Learning is a necessary part of resilient systems. *How prevalent is it and how does it occur? Is it an ongoing process? What limits it?* Reservoirs of knowledge and information – *are they formalised, transient? Is experimentation being encouraged or dampened? What kinds of encouragement (e.g., subsidies) is in place in regard to either promoting novelty, or inducing people to keep on with the same practices? Is innovation evident (e.g., sources, evidence of new products, crop types, markets, institutions)?*

Social and ecological memory (remnant vegetation, long-term data, traditional knowledge and understanding) contribute to adaptive capacity.

What particular aspects of the social system are critical in determining social capacity in this system?

2.4.3 Changes in "capitals"

A useful way to envision the system's resilience and adaptability together, is to consider the levels of and changes in the 'pools' of various capitals:

- Natural capital - nutrients, soil water holding capacity, kinds and amounts of different ecosystem types, e.g., critical refugia (cf memory), species diversity, other?. Some aspects (like invasive exotic species) can lower resilience of desired regimes.
- Financial capital - poor people are less able to respond to certain kinds of crises
- Built capital - states of infrastructure, buildings, machinery, etc.
- Human capital - diversity and levels of education, professions, health. Social memory is a form of social capital (evidenced by the response of a few communities to the receding sea in advance of the December 26, 2004 tsunami – the ones who retained the memory fled uphill).
- Social capital (actually "capacity", rather than "capital") - trust, networks, etc, (see above).

Relatively, are one or two aspects of the above kinds of capitals acting as limiting factors in determining adaptability?

2.5 Cycles of change and cross-scale interactions

Consider the various scales defined for the system in Section 1.4.

Where the system is in the adaptive cycle strongly influences what is, and is not, appropriate for intervening in management. If the system is in a late K phase it is less flexible and less able to absorb influences from the dynamics at scales below or above. If it is in alpha, it is highly responsive to influences from below and above, and therefore to changes that might enhance or detract from resilience in the next r-phase.
What phases of the adaptive cycle does the system, at each of the scales, appear to be in? What are the implications of this for the dynamics and likely future changes in the system at each scale?

You cannot understand or manage a system at one scale. Cross-scale influences can contribute to or detract from the self-organising capacity of the system at particular scales. *What are the major influences from the scales above, and are they constraining or facilitating changes at the focal scale?*

Are there particular aspects of the spatial pattern and/or inter-connections of the sub-divisions at any scale that are important in their dynamics and/or the ways they are used? How do the kinds and levels of connectivity at scales below the focal scale influence its adaptability and capacity to respond?

3. IMPLICATIONS FOR MANAGEMENT INTERVENTIONS

If the assessment is being done on an issue by issue basis, before going back to start on the next issue, pull together the implications of the assessment of this issue for management. If this is an overall assessment, do the same. The aim, before going on to the next step, is to list the implications for policy and management, without attempting any specific recommendations. For example, a threshold in the amount of slowly increasing shrubs in a rangeland, resulting in a regime shift from a grassy to a thicket state, has implications for grazing management; a threshold in the amount of produce required before a processing factory closes has implications for industry policy.

4. SYNTHESIS OF RESILIENCE UNDERSTANDING

Identifying the components of resilience and adaptability (and therefore the points of intervention in the system for managing resilience) is the main aim of the assessment. We are in an exploratory mode at this stage without an established methodology. Learning *how* to do this step constitutes the current research of the Resilience Alliance. Here we present some ideas and pointers which need to be fleshed out in case study workshops. Ideally, for any particular SES, it should be done in conjunction with the stakeholder groups and those who know about the history and functioning of the region. We suggest proceeding as follows.

At this stage there will be one or more models – some quantified, some perhaps still only conceptual. Some may apply to only one of the initially identified issues. The next stage is to *revisit this set of models and change and combine them to include what has emerged in the analysis.* Two key inputs include the system-specific version of Figure 4 and the lists of system attributes, at the various scales that are involved, that are significantly affecting resilience and adaptability.

The desired product here is *a concise statement of the key determinants of the system's resilience, and its present state*. The best format will depend on what has transpired, and what the participants in the analysis like, but a table based on Figure 4 might be an appropriate summary that can be easily referred to in developing the next section.

In this revision of the models the aim is to identify pairs (or even triplets) of alternate basins of attraction that the system can or might be in (Box 1 is a schematic representation). As discussed in Walker et al (2004), the attributes of the system that directly determine the four aspects of resilience are the key system attributes that determine its resilience in regard to that basin of attraction and its alternate(s). The processes or attributes that, in turn, influence this set of key resilience attributes are those that determine the adaptability of the system. A key question is: *What are the system attributes that determine the dynamics of the 'slow' variables, and the positions of thresholds on these variables, noting that different slow variables will be involved in controlling the different kinds of individual regime shifts (in different domains and at different scales) that might exist (as in Figure 4)?* [1]

General vs. Specified resilience

Increasing "efficiency" of agricultural production (as an example) carries with it the risk of reducing response diversity (cf. Elmqvist et al. 2003) and therefore resilience. It is a basic problem inherent in a management approach aimed at optimising for a particular product, or a particular 'state' of a system. In an analogous way, efforts to increase resilience of some system regime to a specified set of disturbances can unwittingly reduce the resilience of that system to other, non-specified (yet to be experienced) disturbances.

This raises the issue of the need to maintain general resilience while engaged in necessary efforts to enhance specified resilience to known threats and disturbances. It is a difficult issue to address because it

[1] Any SES is a highly complex system and the reality is that the stability landscape will have multiple axes, representing a multidimensional stability landscape with multiple basins of attraction, each of which will have a complex and constantly changing shape. Some of the alternate basins might appear along only one controlling axis - ie along all other axes there will be only one possible attractor (this seems likely, based on the principle of limiting factors and the "rule of hand"). It is probably not possible to capture the full set of basins in the multi-dimensional stability landscape in one representation, or model. Hence the need for a set of representations (models) that collectively encompass the significant alternate basins the system can be in. By analysing this set, and paying due regard to any interactions between them, the corresponding set of system resilience and adaptability attributes is identified, as the basis for resilience policy and management.

involves unidentified shocks and unknown costs, but in line with general arguments for the precautionary principle, it is wise to *assess whether changes are occurring that accord with a general loss of resilience, as indicated by the attributes described in Section 2.4.*

Further research

It is useful at this point *to identify crucial areas of data, functional relationships, and models that would significantly improve the analysis and understanding of the system*. These constitute important research areas - BUT, this is not a delaying tactic; the analysis proceeds anyway.

IV. INTERVENTIONS FOR RESILIENCE MANAGEMENT

We asked at the beginning of this assessment how we could know if existing policies, or proposed new policies, are likely to achieve their stated aims (usually some version of high but sustainable yield).

We also need to know if, from a sustainability viewpoint current or planned financial investments are the best ways to be spending the available money.

We now focus on where and how to intervene in the system in order to enhance (or where necessary to reduce) resilience. Three important initial points need to be made:

1. One very important set of possible interventions is what NOT to do – or stopping current activities that are inimical to resilience management.

2. Single interventions are unlikely to be successful, and often amount to partial solutions. It is necessary to think about the set of interventions needed, and how they interact with each other. (We cover this in more detail later, under "interactions and sequencing").

3. The need to be succinct results in this section appearing rather formulaic, and this is not the intention. Again, the process should be iterative and it doesn't matter where it begins. There is no fixed formula.

1. KINDS AND SCALES OF INTERVENTIONS

Interventions can be grouped into four main kinds:

1. Policy and institutions - regulation, property rights, rules, norms, standards
2. Fiscal and monetary - investments (eg in infrastructure), subsidies, taxes, market creation, other economic instruments (Note that subsidies *not* to change, rather than financial assistance *to* change tend to reduce both adaptability and transformability)
3. Management guidelines
4. Education (partly under #2 in the form of investing in development of mental models)

Critical Thresholds and Interventions

Try to place the set of possible regime shifts in priority order for intervention, based on: a) How significant they would be; and b) how likely they are to happen (ie, how close to the threshold are they). Determine for each threshold, in relative terms at least, the likely consequences (costs) of crossing it and the costs and benefits of not crossing it?

Consider both these costs/benefits for each individual regime shift and, referring again to your version of Figure 4, the likely knock-on effects should the threshold be crossed. *Develop a (small) set of critical thresholds that constitute priority attention for intervention.*

Using section 2.4 above (on propositions about attributes), *what are the determinants of each of these critical thresholds?* That is, *which system attributes determine the position of the threshold, and which system attributes are determining the dynamics of the system in relation to the threshold?* These are the attributes that policy and management need to focus on.

The institutions involved in making interventions operate at different scales and it is helpful to consider possible interventions at these scales. It is necessary to iterate between the scales in doing this. An intervention at, say, a state scale may require (or make obsolete) an intervention at a local or farm scale, and *vice-versa*.

One way to begin the process is to *pull together the set of "implications for management" from the resilience assessment, and identify appropriate interventions of types 1) to 4) at each institutional scale* - e.g. state agency, local government, Management Authority, Water Board, NGO, land owner/manager. It is likely that the list gets to be fairly long and complex.
Be *iterative, successively invoking the "rule of hand" to determine which thresholds and associated interventions are of highest priority – which of them are critical.* It is recognised that this list may initially be nothing more than best guesses at how to approach the problem.

It is likely that there is no unique combination of interventions that is "best". Different combinations of market, financial and regulatory interventions may be equally effective in achieving increases in resilience, and the preferred interventions will differ amongst the stakeholders. If there are existing or proposed interventions that are having, or are likely to have, significant effects, it may be useful to start with them, and consider other possible interventions in relation to this set, noting that some of the existing or proposed interventions may have negative effects and need to be "undone".

2. INTERVENTIONS IN RELATION TO PANARCHY BEHAVIOUR

[NOTE; This is very much an area that requires research, particularly by social scientists, and what is offered here is merely a suggestion for how to start thinking about it. The outcome of this final section should be seen as a set of suggested options that will form the basis for an informed discussion amongst the stakeholders – including the policy makers]

Referring back to Section 2.5, the kinds of interventions that are most appropriate (and inappropriate) are influenced by the phase of the adaptive cycle. It is not possible to be prescriptive, but it is important to consider whether there are clear indications for success or failure due to the phase the system is in.

i) Foreloop interventions.
The positive function of foreloop dynamics is building capital, of all kinds. Systems that are too often or too long in backloops do not advance human or natural system wellbeing. Society is generally good at foreloop behaviour (acknowledging problems of equity and corruption), but from a resilience perspective two common foreloop trends may require intervention:

1. Becoming too good at it; not recognising that increases in efficiency of production are reducing response diversity. Maximizing production through increased efficiency often leads to unwanted surprises - collapsed fish stocks, disastrous epidemics (cf. the last foot-and-mouth outbreak in Europe and the UK), etc.
2. Becoming increasingly reluctant to change from what has developed into a successful production system.

Actions that offset these trends and that have been shown to increase capacity during times of rapid change (Olsson et al 2004) include such things as:

- building social capacity and retaining memory in the system, for example by creating social networks that connect institutions, organizations, and/or individuals to build trust
- strategic investments to secure ecosystem goods and services (that are not recognised while things are going well)
- encouraging novelty, experimentation and learning
- facilitating knowledge and information sharing
- providing incentives for stakeholder participation
- identifying and plugging knowledge gaps

ii) Breaking K-phase behaviour
In this phase there is strong resistance to change and it may be too late for education and encouragement. One option is to induce or create small disturbances, to force release of resources and re-organisation, before it happens through an externally induced disturbance.

The aim in foreloop intervention is to either bring about a move back along the axis from K to r, or to induce a small-scale backloop that quickly re-organises into a rejuvenated r phase without significant loss of capital.

Another way to think about this is to identify sub-systems (spatial, or otherwise embedded) of the focal scale, and generate backloops in some of these sub-systems. A strong proposition in resilience theory is that generating backloops at small scales prevents the higher scales from developing into late K phase behaviour.

iii) Backloop interventions
If the focal scale of the system is in a backloop (existing arrangements unravelling, people and capital leaving, ecosystems ‘collapsing’), the main aim is to retain as much capital as possible while fostering and speeding up the re-organisation phase. Bring to an end the unravelling, capital loss phase as quickly as possible, retaining ‘memory’ and resources. What can be done to allow novelty to flourish (this is where investment during the foreloop pays off) and a new r-phase to emerge? It amounts to a trade-off between allowing novelty to flourish as much as possible, and constraining it so that the backloop does not go on too long.

Panarchy interventions
A common cross-scale effect that reduces resilience and that may require intervention is the provision of subsidies from higher scales to enable K-phase behaviour at the focal scale to persist (help *not* to

change, rather than help *to* change). Consider the interactions amongst the institutions at different scales (identified above) and examine them in terms of needed changes that may call for intervention.

Based on the above considerations, *in terms of adaptive cycle dynamics, is it clear where the system is in the cycle? Does resilience management call for:*

i. *foreloop type actions (including education),*
ii. *breaking K-phase behaviour (creating small disturbances? Preparing for an inevitable release phase?),*
iii. *backloop interventions (retaining capitals, facilitating experiments and innovation)?*

In terms of panarchy behaviour, *what cross-scale interventions are called for?*

3. INTERACTIONS AND SEQUENCING

Considering the set of priority interventions identified in 1) and 2) above, are there any sequencing issues involved in implementing the interventions? Obvious ones would be ensuring appropriate changes in regulations are in place before recommending management changes, but there may be less apparent interactions amongst the interventions (see for example Stiglitz's (2002) criticism of the lack of sequencing of the IMF's interventions in SE Asia that exacerbated the East Asian economic collapse at the end of the last century). Sequencing within ecological, economic and social interventions, and between them, needs to be considered before any are implemented. *Place the interventions into sequential order and examine the consequences, using the insights gained form the models you have developed and your understanding of panarchy effects.*

4. ADAPTIVE MANAGEMENT

Adaptive management is an approach captured in the phrase 'learning by doing'. It is a learning-based approach to resource management which views policies as guesses or hypotheses, and actions as ways of testing those guesses. The main point of an adaptive assessment is to try to define what is known and what is not known about various management issues. It makes explicit the assumptions underlying management. Management actions can then be structured to test these assumptions (system understanding), while solving management issues. In doing so, adaptive assessment attempts to fill the gap between knowledge and action.

Box 6 provides an account of the process and the difference between passive and active adaptive management.

BOX 6
ADAPTIVE ASSESSMENT AND MANAGEMENT

The core feature of adaptive assessment and management is the development of a model of some kind (a conceptual mental model, or an explicit mathematical one) that attempts to integrate understanding from various disciplines. The model also provides a framework for revealing the assumptions and sorting through alternative explanations or hypotheses about system dynamics. As such, the model is used to pose better questions about how the system might behave, rather than attempt to predict policy consequences. These questions are evaluated or tested over time through management actions, monitoring the results, and updating the model accordingly. Only by iterating in this way can you develop a management program that delivers desired results.

Adaptive management is of two basic kinds (Walters 1986); passive and active. In passive adaptive management you use whatever information comes from management actions to improve your model as best you can. In active adaptive management you deliberately take actions - do things to the system you would not normally do in the course of trying to achieve management aims, in order to learn better how the system works. You do experiments, as part of your management, in order to learn about what will happen under certain levels of use, or certain environmental conditions.

Active adaptive management is far more powerful as a way to discover (for example) where thresholds might lie. It calls for varying the levels of resource use to see, and to carefully monitor and record, the response in the resource base. Where the system consists of lots of spatially distinct sub-units it is relatively easy to devise 'safe' experiments, in the sense that if one of them damages a sub-unit the damage is limited. Designing acceptably safe experiments for a particular system needs careful thought. The great advantage that comes from the combination of passive and active adaptive management is that the constantly improving model enables management to achieve its aims with much greater reliability. This applies whether the aim is to maximise yields, or to maintain resilience. Each requires an underlying model. And just to make a point, if the model for maximising yield assumes that the system is globally stable (ie, it has only one stability regime, and however much it is used or harvested, it will always be able to return to its one notional equilibrium state) when in fact it has a threshold effect that leads to an undesired regime shift, active adaptive management will greatly increase the likelihood that you'll discover that the linear single-regime model is wrong, and that maximising yield will need to take the existence of the threshold into account. Perrings and Walker (1997) give an example of how knowledge of a threshold changes the pattern of resource use in an optimal use context.

To begin setting up an adaptive management program it is useful to summarize the alternate regimes within the focal system. And it helps to think about regimes that occur in the ecological domain, economic domain, political domain and social domain.

With this information, and referring back to section 2.2.1 ("Further research"), *the next step in the procedure calls for the design of an adaptive management program, as an integral part of the planned interventions.* It will likely be necessary to test the form and positions of identified thresholds for at least some of the regime shifts listed, and experiments of this kind involve costs, sometimes in the form of foregone profits where reduced levels of use are one of the 'treatments'. This will be especially important in tests to determine if the system is in an undesired regime, and what it will take to restore it to a desired one. The allocation of costs is part of the intervention program.

Adaptive management has developed in ecosystem management and applying it to social systems involves an extra layer of complexity, since experimenting in social systems may raise additional legal and ethical concerns. It is still important to consider, however, and as an example of how it may be approached, the "Knowledge Network for System Innovations and Transitions" (http://www.ksinetwork.nl/), in the Dutch Research Institute for Transitions, describes different kinds of social experiments.

5. IS TRANSFORMATION CALLED FOR?

The final step in this resilience assessment is to consider whether the information gained calls for radical change. *Has the option for resolving problems through adaptation gone?* If there is little chance that an acceptable outcome can be achieved through managing the thresholds in the system (either preventing regime shifts or engineering them so as to move into desirable regimes), then intervention must focus on how to re-define the system; how to become a different kind of system.

Transformation is hardest to achieve. The key with transformation is the development of new approaches, new mental models, or the reframing of issues (for example, in the Kristianstad region in southern Sweden, changing from a "water poor" to a "water rich" view of the wetlands). It requires:

i) Using disturbances to generate transformations. Those disturbances can be deliberate or accidental. That is, many activists want to create destruction of existing rules, behaviours, etc., because they want to force a change by creating a disturbance. Many resource systems use 'natural' disturbances such as storms, fires, pest outbreaks, to initiate a transformation. This is done by either inventing new strategic alternatives, or having some that have been developed before and are ready for use when the opportunity arises.

ii) A shared understanding and (if possible) agreement amongst all stakeholders on:

- the benefits of being in the transformed system - financial and other (lifestyle, etc.)
- the costs (financial and other) of *not* transforming
- the costs *of* transforming
- the likelihood of having to bear the costs of not transforming

iii) A change in institutions (rules, norms and regulations) that will in turn favour change in resource use, rather than penalising it. This requires examining all forms of taxation and subsidisation related to the current way the system functions, as well as local, regional , State and Federal regulations regarding resource use (, e.g. for water use, land use (land clearing, crop types permitted, animal movements, harvest levels of natural resources), caps on discharges of pollutants or concentrations of salt, etc.

6. CONCLUDING COMMENT

We conclude with the same comment that opened this section on interventions. The intended outcome of the interventions assessment is a set of options that will allow the SES stakeholders to hold an informed discussion on what they need to do about the resilience of their region.

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Assessing and managing resilience in social-ecological systems: A practitioners workbook

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Resilience Alliance

The Resilience Alliance

The Resilience Alliance (RA) is a research organization comprised of scientists and practitioners from many disciplines who collaborate to explore the dynamics of social-ecological systems. The body of knowledge developed by the RA encompasses key concepts of resilience, adaptability and transformability and provides a foundation for sustainable development policy and practice.

RA members are leaders in the ecological and social sciences, covering a range of disciplinary expertise. The research program supports rigorous testing of theory through a variety of means, including: participatory approaches to regional case-studies, adaptive management applications, model development, and the use of scenarios and other envisioning tools.

The work of the RA fortifies a paradigm shift in natural resource management from top-down, command-and-control optimization to the promotion of resilience and self-organization. RA members have extensive experience engaging stakeholders involved in resource management and planning processes in an Adaptive Environmental Assessment and Management (AEAM) framework as well as in the developing area of adaptive governance.

The RA is continually exploring ways of building connections among researchers and practitioners to improve sharing of knowledge and ideas. Established in 1999, the RA's members are based at universities, government agencies, and NGOs in eight countries. To learn more about the Resilience Alliance visit www.resalliance.org.

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Preface

The challenges faced by natural resource managers and practitioners today are increasingly complex. Solutions that address individual problems as they arise may be successful in the short term, but they may also set into motion feedbacks that come into play later. Likewise, piecemeal interventions do not prepare a system for dealing with ongoing change and future shocks.

An approach to managing natural resource systems that takes into account social, ecological, and economic influences at multiple scales, accepts continuous change, and acknowledges a level of uncertainty provides the potential to increase a system's resilience and adaptive capacity.

Decades of theoretical research and case study comparisons by members of the Resilience Alliance and other researchers, have contributed to a better understanding of the dynamics of complex social-ecological systems. A set of key concepts underlying resilience thinking provide a framework for assessing the resilience of natural resource systems and for considering management options to set the system on a sustainable trajectory. This workbook has been developed specifically to provide guidance to people engaged in natural resource management, through a set of activities designed to explore system parameters and management options for their own system of interest from a resilience perspective.

Adaptive capacity/Adaptability – *the capacity to adapt and to shape change. Adaptability is the capacity of actors in a system to influence resilience. In a social-ecological system, this amounts to the capacity of humans to manage resilience.*

Resilience – *the ability of a system to absorb shocks, to avoid crossing a threshold into an alternate and possibly irreversible new state, and to regenerate after disturbance.*

Social-ecological system (SES) – *an integrated system of ecosystems and human society with reciprocal feedback and interdependence. The concept emphasizes the 'humans-in-nature' perspective.*

Why do we need a workbook?

Scale – *any measurable dimension (such as space or time). Structures can be measured in terms of spatial resolution (minimum) and extent (maximum), e.g. a farm covers 100 hectares. Processes can be resolved in similar temporal terms, e.g. a cyclone persists for 24 days. For the purposes of a resilience assessment, a focal scale of the social-ecological system of interest is usually determined from among: landscape/local scale, sub-continental/sub-regional, continental/regional, and global scale, over a specified period of time.*

The overriding motivation for developing the workbook and accompanying resources is a two-fold concern about the future. Firstly, we see many systems around the world in which other frameworks for resource management have failed. We see failures at local scales, where fish stocks become extinct, grazed paddocks become unusable, and soil fertility becomes degraded. At larger scales, regional attempts to irrigate dry landscapes or drain wetlands can result in salinization, water pollution, and loss of aquatic habitat. At a global scale, loss of biological diversity and climate change are daunting challenges of our times. Many of these changes are related to attempts to control nature, which in turn lead to unexpected results. Our second concern is about seeking a future that is sustainable. Recent global assessments (Millennium Assessment, 2005) suggest that current trajectories are not sustainable and that resources critical to sustaining human lives are being degraded across the planet. How these resources are managed, at local, regional, and international scales must change in order to reverse current unsustainable trends. One approach to making necessary changes in how resources are managed involves considering an alternate worldview.

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Introduction

People perceive their environment in many ways. Their perceptions are largely based upon life experiences, education and training, and cultural traditions. Moving beyond this foundation and attempting to view our environment from a new or alternate perspective can be challenging but is often also illuminating. Consider for example, our understanding of cycles in nature. Some of those cycles are indisputable, such as the cycles of night and day, or of the seasons. Other, longer term cycles such as those of tropical cyclones, profoundly affect life but we ride with them. Some cycles can be modified or managed by people for their own purposes. For example, the century-long natural cycle of succession and renewal of forest stands in a landscape can be converted to a more rapid cycle involving pulp production and tree planting. In marine systems fish stocks may be managed according to a variety of factors including the age structure and therefore lifecycles of particular species. Hence, managing natural refuges and parks, forests, grasslands, and aquatic systems, managing the extraction of resources, involves managing cycles.

People base management actions on how they think the world works (and how they want it to work). The idea of managing social-ecological systems in the context of cycles, and in fact managing the cycles themselves, is one such model or way of thinking about managing human-natural systems. We use the daily cycle to plan our day, when we sleep, when we wake, when we eat and when we go home. Annual cycles guide other management actions, such as decisions about budget allocations, projects and programs.

People charged with making and implementing plans do so based upon their world view, which is also referred to as a 'mental model'. These mental models can be open and explicit, or tacit and implicit. This workbook is about recognizing and understanding a mental model that differs from many currently in use by resource managers.

> *Management actions are based upon models. Resilience is one model that incorporates dramatic and surprising changes and alternate system states.*

This workbook represents a worldview that emerged as interdisciplinary teams of scientists have attempted to learn from past environmental failures that have been difficult for societies to deal with, like the collapse of New England fisheries. Some aspects of this worldview will be familiar to resource managers, but other aspects may be new. Generally this worldview requires that natural resource management issues be evaluated from a broad systems perspective that includes both ecological and social factors, multiple spatial and temporal scales, and the inclusion of surprising dynamics.

Who should use this book?

The workbook is aimed at practitioners, managers, and stakeholders who:

- Are concerned with the long-term horizon and welfare of a region
- Engage in strategic planning and management of natural resources
- Are open to exploring an alternative worldview
- Have a broad understanding of a particular social-ecological system
- Have the desire or ability to influence decisions and actions in the system

The workbook is designed to assist those who are interested in: resource use within specific areas, resolving specific resource problems (e.g. reconciling multiple uses or rehabilitating endangered species), or developing and implementing specific management goals (e.g. conservation, economic development, balancing trade-offs).

The workbook is structured to help guide a process of inquiry and action for those who are interested in applying the concept of resilience to complex resource problems within a region. In broad terms, the workbook is intended to help managers and other stakeholders address the following questions:

(i) Are existing policies, or proposed new policies, likely to achieve stated aims (which may include some version of high but sustainable yield)?
(ii) In terms of achieving sustainable outcomes, are current or planned financial investments the best ways to spend the money?
(iii) (Bringing these two together) Are the existing strategic and operational plans for the region (explicit or implicit) robust to future uncertainties?

In formulating this workbook, we draw upon a body of knowledge called resilience theory. Resilience theory provides a mental model for thinking about the management of social-ecological systems. It provides strategies for buffering or coping with unexpected change. Rather than attempting to control natural resources for stable or maximum production and short-term economic gain, resilience management assumes an uncertain and complex context for natural resources and seeks to achieve sustainable long-term delivery of benefits. Building resilience offers some protection for maintaining this flow of ecosystem goods and services and for coping with unexpected shocks to the system, by nurturing a capacity to learn and to adapt. Managing for resilient systems is a necessary component for achieving sustainable futures.

The framework for a resilience assessment is based upon the concept of a system. A system is a combination of elements that interact to form a more complex entity or whole. For example, the human body is a system of cells, tissues and organs. A systems approach is holistic in that it does not focus exclusively on a detailed understanding of parts, but on key components that contribute to dynamics of the whole entity. The word ecosystem is a contraction of the phrase ecological systems, which refers to an entity comprised of interacting living and non living components. Resource systems refer to systems of people and natural resources.

Resource problems and management issues are not just ecological, social, or economic issues, but have multiple integrated elements. These systems—in which cultural, political, social, economic, ecological, technological, etc. components interact are referred to as social-ecological systems. We use the phrase to emphasize that this is a system that focuses on the interactions between the (non-human) natural world and the human-constructed world.

The concepts and activities that comprise this book were developed to help people who are involved in managing social-ecological systems develop a mental model that accepts the dynamic nature of these systems and their inherent occasional unpredictability. No resource system, whether managed or not, is a static entity. Some system changes are a result of processes occurring outside the system of interest, such as annual cycles of sunlight and temperatures that influence how fast trees grow. Other changes result from processes or factors internal to the system, such as how the abundance of trees in a forest can influence the spread of a pest or disease. Often people intervene and attempt to control change in their systems in order to meet specific goals. For example, foresters manipulate tree density and soil fertility and control pests in order to increase production of timber or fiber. Such interventions can lead to unexpected results. In this workbook we suggest ways to look for and anticipate direct and indirect effects of human actions, as well as how to cope with surprising outcomes.

How to use the workbook

The workbook is designed to guide individuals or small groups through a process to assess the resilience of natural resource systems, (i.e. the capacity of the system to recover from disturbance) in order to guide management planning. It is organized around a set of key concepts with questions and activities that assist the user in exploring resilience concepts as they apply to their own system of interest. The workbook uses an issues-based approach. Specific issues or concerns about a natural resource system are used to focus and direct the resilience assessment.

The workbook is organized around key concepts of resilience theory that have been divided into workbook sections and grouped into five chapters. The chapters guide a progression from defining your system, identifying alternate states and thresholds, evaluating dynamics based on system cycles, probing the system's adaptability and finally planning interventions.

Each section of the workbook:

- deals with a specific key concept and begins with a statement that links the concept to managing resilience
- includes a checklist of what will be achieved upon completion of the section
- introduces the concept by way of an example (from a variety of natural resource systems)

- lists in summary format the key messages pertaining to the concept and example
- includes an extensive set of questions and activities (*Resilience Assessment*) to guide the reader to apply the concept to their focal system
- builds upon and integrates knowledge and information from previous sections

The Resilience Assessment component of each section is the 'work' part of the workbook. Our estimates, based on previous workshops, suggest that a minimum of three full days is necessary to complete the assessment, and then (depending on what the assessment comes up with) further work may be needed to collate information, develop models, conduct interviews, etc. It is highly recommended to include a preparation and data-gathering phase as well as to read the workbook in its entirety prior to convening a group to begin the assessment. That being said, there is no single best way to conduct a resilience assessment and no best place to begin. While the order in which we present it makes sense, some have found that it is best to move back and forth in the process. The key message is: don't get bogged down on one particular aspect. Move on, and then return later. If an activity is irrelevant to a particular system, move on. As you progress through the workbook you may find it necessary to revise your response to questions or activities in previous sections. The user is encouraged to iterate among chapters.

The workbook may be used in a workshop setting, involving practitioners and experts in small groups, or it may be used by individuals who work alone or with others through remote networks. In a workshop setting, we suggest having a moderator or navigator who can help with questions, guide discussions, and coordinate activities.

Caveats, rules of thumb, and general advice

- This is an organic document, and as such it should evolve over time. We welcome feedback on other ideas, approaches, or required improvements to this workbook.
- An assessment of resilience is never complete. It must be revisited regularly as system dynamics change and as understanding grows. The workbook activities are intended to further a process, rather than produce a final product.
- There are many alternative ways to assess resilience, and alternative leadership strategies to use in having groups of people explore resilience and system dynamics.

- Even if you don't succeed in fully assessing resilience, the development of a community that can think about change, social-ecological systems, etc. should be seen as progress (you will have laid the groundwork for a more comprehensive assessment of resilience at some point in the future).

- We encourage innovation and creativity. This often involves questioning assumptions and suspending boundaries.
- We encourage openness and cooperation in the exercises, but this should not preclude conflict and disagreements. In fact disagreements can be useful for highlighting issues of concern. What is important is to create an open atmosphere for expressing and resolving dissent and disagreement.
- Resilience is a critical property that provides some insurance for mistakes. That is why it is important to understand, nurture, and in some cases restore resilience.
- Seek and evaluate actions that are 'safe to fail' (i.e., if they fail it won't be catastrophic). Encourage small scale tests that are safe for the ecosystem, individuals, and institutions.
- Confront complexity. The key question is not whether to simplify but how to simplify complex systems for assessment and actions.
- Question terms and expressions. We've tried to avoid using jargon. Instead, we've defined and explained terms throughout the book when they are first used and provide a glossary. We also offer here, as a start, a short list of key terms that need to be understood before launching in to the process.

1 The Resilience of What, to What?

1.1 Bounding the System: Describing the Present

1.2 Expanding the System: Multiple Scales

1.3 Linking the Past to Present – Historical Timeline

1.4 Resilience to What? - Disturbances

The first step of a resilience assessment involves defining the system of interest and specifying issue(s) of concern. This is accomplished by describing the key attributes of the system (the resilience of what) and the main disturbances and processes that influence it (the resilience to what).

1.1 Bounding the System: Describing the Present

Managing resilience requires integrating ecological, social, and economic understanding.

One of the early insights of resilience research was the need to examine coupled social-ecological systems, emphasizing that people are part of nature. Understanding the component pieces of a system doesn't ensure understanding the behavior of the system as a whole. Mastering a more holistic understanding of the system also means respecting the knowledge that those with different training and perspectives bring to the table.

Upon completing this section, you will have:

- Identified the main issue(s) in the system that you are going to address.
- Determined appropriate spatial and temporal boundaries for your focal system.
- Identified the critical actors and natural resources in the system.
- Listed the primary management agencies, policies, and property rights mediating use of those natural resources.
- Devised a plan for obtaining critical ecological, social, and economic information.
- Identified management goals for your system, taking into consideration the goals and underlying values of a diversity of stakeholders.

Bounding and Identifying Issues in the Grand Canyon

The Grand Canyon is one of the largest geomorphic features on the planet, created over the past 6-10 million years by the Colorado River (Figure 1.1.1). The Grand Canyon can be used to help illustrate the way in which issues of resilience can be identified and used to establish tentative bounds for assessment.

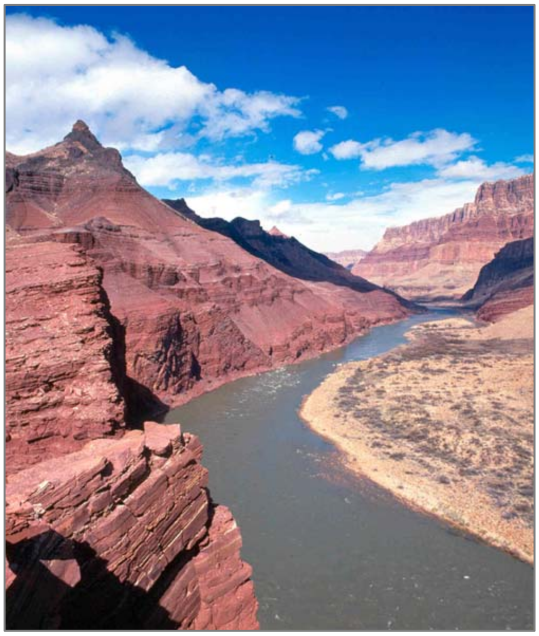

Figure 1.1.1 Grand Canyon. Source: U.S. National Park Service

Over the past century dams have been constructed along the river in order to stabilize the water flow, generate electricity, and to provide water to the arid regions of the southwestern United States. Flood protection and water for human use (consumption and irrigation) are the primary purposes for controlling the flow of water in the Colorado River. The revenue from the sale of electricity pays for the initial capital cost of dam construction and a portion of ongoing operations, as well as environmental research and management activities. Yet the construction of the dams has resulted in dramatic changes in the ecological, social and political regimes.

This region provides an example of how to begin assessing issues of resilience. That assessment should begin with identifying key resource issues, and describing the relevant geographical boundaries and time horizon.

Boundaries

The Grand Canyon is in a reach of the river bounded upstream by the Glen Canyon dam and downstream by the Hoover dam. The dams provide a way of bounding the river system for analysis, in terms of control points of key ecological processes and administration. Yet it is not easy to use these structures as bounds, because some ecological processes extent far beyond the dams, while others do no. Water, nutrients and biota all flow through the system, originating upstream, while sediments no longer nourish the Grand Canyon reach of the Colorado River.

The time horizon of assessments can be established, and are generally related to the issue being considered. The time domain is described along with each issue.

Management Issues

Prior to damming the river, it had extreme flow variation, large sediment loads that colored the water red (hence the origin of the name, Colorado River), and seasonally large fluctuations in temperature. Today, downstream of the Glen Canyon Dam, the altered river system has relatively stable flow, clearer water, and a near-constant temperature year-round. These changes in turn have had unforeseen consequences, such as the extirpation of seven species of native fish, the endangerment of four others, and a loss of habitat types. The water flows of the Colorado used to vary at time scales of months to decades, with a strong annual cycle. Currently, the largest flow variation occurs on a daily basis, associated with releases to generate electricity.

Present management challenges include how to restore sediment inputs and retain current sediments within the system. The sediments are deposited on the banks during high flows, and erode back into the water during low flows. Keeping sand on the banks is important to the large recreational community who camp on the beaches, and to the conservation of cultural artifacts along the river.

Another management issue involves the declining populations of the humpback chub and kanab amber snail. Water temperature, flow, tributary inputs, and predation by non-native fish all contribute to their continuing endangerment. Since these two species receive special protection under the U.S. endangered species act, their recovery is a primary management goal and any management action must not harm the populations. Hence mitigation and amelioration of dam effects are primary objectives of management. As such, the time frame for assessment and issue resolution is on the order of multiple decades.

The canyon has a long history of human habitation and cultural values. For thousands of years people have used the river and surrounding land. Many sites are of significant cultural and historic value where legacies of past use still persist. Maintaining these cultural sites is another concern of managers.

The management of the Colorado River and Grand Canyon involves a complex of institutional structures and processes. A number of laws and treaties lay out rules for allocation of water among the various users. The federal government is represented by half a dozen management agencies, including the Bureau of Reclamation, National Park Service, U.S. Fish and Wildlife Service and Bureau of Land Management. Several native American tribes also participate in management decisions about the river and surrounding areas. At least six states participate in the management of this reach of the river. Non-governmental organizations represent conservation interests in the river, recreational and guide fishers, and rafting and boating groups, among others.

The institutional components of managing the Grand Canyon portions of the Colorado have become more integrated. That is, some groups are engaged to protect the ecological values of the system, such as the US Fish and Wildlife Service that has responsibilities for threatened and endangered species. Similar non-governmental organizations exist, such as the Center for Biological Diversity. Other groups, such as the Western Areas Power Administration, organization of Fly fishers, or the River Rafting associations represent economic features of the system. Other groups or agencies such as the US Park Service, Bureau of Reclamation have missions to integrate the ecological, social (including cultural), and economic dimensions of resource issues.

Key Messages

- To begin an assessment, it is useful to determine bounds to the system of focus (*focal system*).

- Identifying relevant boundaries of a system can be related to a specific key issue; then a geographic scope and time horizon of that particular issue can be approximately determined.

- There is no perfect way to set the boundaries of a system. Initial assessments may need to be changed as understanding of the system deepens.

- Any system is influenced both by things that lie outside of its boundaries, as well as by what lies within the boundaries. A full resilience assessment must consider the *cross-scale* interactions of system components across boundaries. In this section, we will primarily consider the focal system and its sub-components.

- Once the system boundaries are determined, consider only the critical components. It is useful to reassess what is and isn't critical as understanding of the system and issue(s) advances.

- It is necessary to consider ecological, social, and economic features of the system in the resilience assessment.

- Achieving an integrated understanding of ecological, economic, and social features of the system means including a diversity of perspectives, from those formally trained in particular disciplines to those with informal but insightful understanding of the system.

Cross-scale – *Influences between the dynamics of systems at one scale and the dynamics of those that are embedded in it or enfold it.*

In the assessment that follows you will define the focal system and its key components. The focal system includes: natural resources, the people managing and using them, the institutions governing access and resource allocation, as well as commercial and non-commercial values.

Resilience Assessment

What are the main issues that need to be addressed? There may be one central issue, or there may be a set of issues. In considering the main issue(s) to be addressed, identify valued attributes relating to the issue(s). For example, in the Grand Canyon one issue is the declining populations of the humpback chub and kanab amber snail, making the snail and fish or more generally, native biodiversity, a valued attribute of the system.

Issues can be addressed one by one or all together. For each issue, what is a reasonable geographic boundary for your system? You may wish to obtain a map (or sketch a map—accuracy is not critical here) and draw a boundary around this system. This boundary defines the extent of what is called the focal system. It is important to note that existing political or even ecological boundaries may differ in relation to resilience regarding the key issues at hand and therefore may not necessarily be the most appropriate ones for resilience management.

Identify important social components of the system (population centers, political units, cultural areas, and areas under the management of different agencies), institutions (land conservation, water management, etc.), ecological components (lakes, forests, rivers, grassland, others), and economic components (croplands, grazing lands, tourism destinations, others) and either draw them on your map, or list in a table.

Given the central issue or challenge, what is an appropriate time span over which to examine this system? Consider how far analysis should extend into the past, and into the future. For example, the time span may reflect a planning cycle or be determined by a natural cycle, etc. You may wish to return to your initial thoughts here after completing a historical timeline in section 1.2.

Referring to a list of social, ecological, and economic components of the system, the following set of questions is designed to help further define these various components.

The natural resources

What are the main natural resource uses in the focal system (those that are important and need to be included in the assessment)? Consider economic, subsistence, recreational, cultural, and conservation uses in formulating your answer. Consider also the perspectives of others not present (including future generations)—are there uses they would have added to the list?

Are there critical non-marketed ecosystem goods and services (i.e., the benefits that society derives from ecosystems) that are derived from the region? These types of services benefit people and might include provision of clean water, carbon sequestration, maintenance of unique species, etc. (See Appendix X for a listing of ecosystem services you may wish to consider.)

The People
Who are the key stakeholder groups in the region (particularly with respect to policy, management and use of natural resources)? Consider including future generations in your analysis. How might their values and goals for managing natural resources be considered?

Are there major conflicts between stakeholders, particularly with regard to the central issue you have identified above? Are there important points of agreement? Briefly outline these conflicts and agreements.

What is the economic status of each group? Are people generally wealthy or poor? To what extent are their options constrained by lack of financial resources?

Can you identify individuals or organizations that have key leadership roles with respect to the issue of interest to your group?

Is learning and innovation a strong or weak feature of the community? What are the sources of learning and innovation? Take into consideration different forms of knowledge (e.g. traditional knowledge).

Learning and innovation - *Learning involves the comparison of mental models with data and information from the world. At least two types of learning have been described: incremental and transformational. Incremental learning can occur when information and data are used to evaluate ongoing plans, models and policies. Ongoing monitoring programs can be used to evaluate whether proposed management actions are achieving desired goals. In this case, the underlying mental model or scheme is fixed. Transformational learning occurs when underlying models, schema or paradigms change. This type of learning occurs after an environmental crisis, where policy failure is undeniable. It requires innovation in the form of development of new ideas, models and policies. Transformational learning is also described as evolutionary learning where not just new models or schema are developed, but also new paradigmatic structures that lead to new sets of policies or management actions.*

Governance
What are the property rights in your focal system? Are there mainly public lands (waters), private lands (waters), common property lands (waters) or a mixture of all three? What are the access rights on these lands (water bodies)? Do the different kinds of tenure conflict with or complement each other?

What organizations control or manage the critical resources in your focal system? What are the relationships between these organizations (pecking order, etc.)?

Are there other, informal institutions that are important with respect to resource use? For instance, homeowner's associations, fishing clubs, bird-watching groups, local norms or taboos etc. may all exert some influence over resource management decisions.

Where does the real power lie? Who has the power to influence your issue?

Are there key policies, laws or regulations governing resource use that enhance or constrain flexibility to manage resources and issues that arise? Keep in mind the key issue(s) of the focal system on which you are focused.

What information were you missing for the analysis above? Devise a plan for obtaining the information. Are there key individuals/groups who should participate in the assessment? List any **Action items**.

1.2 Expanding the System: Multiple Scales

Managing resilience requires managing systems at multiple scales in space, time, and social organization. A more complete understanding of any social-ecological system can be gained by knowing something about what is happening in systems at smaller scales and larger scales and how this hierarchy of systems interacts across space, time, and social organization.

Upon completing this section you will have:

- Identified the critical economic, social, political, and ecological scales that operate above and below your focal system.
- Identified information and data needs, and devised a plan for acquiring that information.

Scales of Structures, Scales of Processes: The Great Barrier Reef, Australia

The Great Barrier Reef provides an example of how to identify cross-scale structures and processes that influence resilience. Running 2000 km along the northeast coast of Australia the GBR is the largest coral reef system in the world, covering an area of about 350,000 km^2. The reef system is comprised of about 3,000 individual reefs, and is structured and influenced by processes that occur across a range of scales- from seconds to millennia in time and from fractions of meters to the globe. Human-mediated processes also span multiple scales, from harvesting individual organisms such as sea cucumbers, snails, and fish, to regional-scale land use that alters nutrient and sediment inputs, to global warming that raises ocean temperatures and causes coral bleaching.

Ecosystem Scales

Figure 1.2.1 Underwater photograph of a segment of the Great Barrier Reef – image covers a scale of multiple meters. Source: James Cook University

A coral reef can be described over a broad range of spatial scales. Assemblages of multiple coral species comprise reefs. Figure 1.2.1 shows the structure and diversity of a segment of reef that covers a window of a few meters. At this scale, the individual corals are not seen, but rather the forms generated by different coral colonies. At larger windows – hundreds of meters, (figure 1.2.2), the corals and colonies are no longer identifiable, yet the patches of corals can be seen. Yet the entire reef comes into view at scales of a few kilometers (figure 1.2.3).

The reef structures shown across these scales are subjected to broader-scale processes. Disturbances, such as tropical cyclones, tsunamis, crown of thorn outbreaks, and warming events occur at scales of thousands of kilometers. Yet following these disturbances, other factors, such as over-fishing, climate change, or disease can eliminate local larvae sources, thereby limiting the ability of reefs to recover at local scales. Without larval sources these reefs can undergo phase shifts to an algae-dominated state. Species with larger dispersal ranges can re-colonize areas where local larval sources no longer exist. For this reason, maintaining connections between reefs that accommodate how far species are able to disperse, contributes to a system's resilience.

Disturbance – *In ecological terms, disturbance is a relatively discrete event in time, coming from the outside that disrupts ecosystems, communities, or populations, changes substrates and resource availability, and creates opportunities for new individuals or colonies to become established.*

Figure 1.2.2. Aerial photograph of a segment of the Great Barrier Reef – image covers a scale of hundreds of meters. Source: James Cook University.

Figure 1.2.3. Aerial photograph of segment of the Great Barrier Reef – image covers a spatial scale of multiple kilometers.

Degradation of a number of small reef patches can lead to larger-scale collapse. When a reef flips to an algal-dominated state, it can no longer supply larvae to surrounding areas. As subsequent disturbances occur, with fewer larval sources, more reefs shift to algae-covered rubble. A cascade of such phase shifts can dramatically increase the size of the altered area.

Scales of Humans and Management
Other impacts on the system such as fishing, may be felt locally yet can be driven by processes happening at a variety of scales and across multiple domains (e.g., social, economic, and ecological). In the case of fishing, complex interactions involving fish stocks, ease of access, market demands, and rules and regulations, among others, may be all influenced by processes and dynamics at local, regional and global scales.

Reef-wide concern over the impacts of drilling and mining led to the establishment of the Great Barrier Reef Marine Park Authority in the mid 1970s. This federal funded institution focused on restricting activity throughout the entire reef area. Over the past three decades a multi-scale management structure has developed that links local advisory groups with state and federal agencies. The Park authority had assumed that the sheer size of the entire barrier reef would be resilient in the face of any of the disturbances.

However, by the late 1990s, spurred in part by reports of large-scale reef collapses in the Caribbean Sea, scientists became concerned that an increase in bleaching events (and other unknown effects of climate change), as well as increased fishing pressure would make the reefs in the GBR more vulnerable to a loss of resilience. Using new analyses of long-term monitoring data, and the above arguments, managers went to parliament to change the scales of management. Parliament acted, which resulted in rezoning the entire GBR and a net increase in protected areas.

Key Messages

- Complex social-ecological systems operate across a range of scales. Even if the primary interest is managing a particular focal system, one must understand the ways in which larger systems influence the focal system. One must also understand how the dynamics of the focal system are influenced by the smaller systems it comprises.

- In some systems, larger things, such as reefs, tend to change more slowly or less frequently. Smaller things, such as individual corals, tend to change more rapidly or more frequently (relative to change at the reef level). In ecological systems there is a relationship between spatial and temporal scales. In general, large = slow and small = fast.

- Scale relationships are not as clearly defined for other systems. Social organizations at smaller scales, such as households, may actually change their characteristics less frequently than social organizations at larger scales, such as forms of government. Physical systems such as typhoons can cover broad areas, yet occur at relatively short time scales.

- Insight into the dynamics and structures of coupled systems can be gained by examining different ranges of scales around a focal scale. Processes at larger scales, such as global warming, flood/drought cycles, or governmental change and processes at smaller scales, such as nutrient cycling, or individual fisher's behavior should be evaluated. It is the cross-scale interactions that can dramatically influence the system being studied.

In the following assessment you will identify the critical scales above and below your focal scale. The resilience and sustainability of systems depends on how these different scales interact with each other—what are sometimes called *cross-scale interactions* (see section 3.2).

Resilience Assessment

Describe the key features of organizational scales above and below your focal scale that are critical for understanding the *social context* of your issue or challenge. What are the higher and lower level policy structures or groups (both governmental and non-governmental)? What are the organizations, above and below your focal scale, that deal with cultural issues or social values and what are the major interactions they have with your focal system? Enter a brief summary in the table below.

Describe the key features of scales above and below your focal scale that are critical for understanding the *economic context* of your issue or challenge. These may be different than those described above (for instance, you may decide that the global scale is relevant for economic impacts in your system, while the largest critical social scale is the nation). Why are these appropriate critical scales? In other words, what are the major influences on or interactions they have with your focal scale? Note also that economic features may relate to cash economies and/or subsistence economies.

Describe the one or two scales above and below your focal scale that are critical for understanding the *ecological context* of your issue or challenge. Again, these may be different than those described above. Why are these appropriate critical scales? In other words, what are the major influences on or interactions they have with your focal scale? Keep in mind that a resilience assessment may be part of a process to change current management practices and as such one should be careful not to pick ecological scales that only bolster current practices.

What critical data or information (in the ecological or social realm) are you missing for the other scales you have described? List how you would go about filling these information gaps as **action items**.

Table 1.2.1 Multiple scale characteristics linked to the focal system
Note: You may not find it necessary to fill in all cells; this will depend on how many scales and domains you are choosing to analyze.

Domain	Scale	Describe the scale	Describe processes that influence focal scale
Social	Larger		
	Large		
	Focal		
	Small		
	Smaller		
Economic	Larger		
	Large		
	Focal		
	Small		
	Smaller		
Ecological	Larger		
	Large		
	Focal		
	Small		
	Smaller		

1.3 Linking the Past to Present: Historical Timelines

Managing resilience requires understanding how historical system dynamics have shaped the current system. Social-ecological systems are dynamic and the changes they undergo are sometimes slow and predictable and other times fast and unforeseen. Having a broad overview of system change through time can reveal system drivers, the effects of interventions, past disturbances and responses.

Upon completing this section you will have:

- Constructed an historical timeline of your focal system that highlights significant events and changes.
- Identified connections between significant events across scales.
- Characterized any patterns of change in the focal system over time with respect to specific domains of influence.
- Devised a plan for reporting, storing, and disseminating the information produced through the workbook process.

History of Everglades Water Management: Crises and Reconfiguration

Historical profiles of social-ecological systems can be useful in identifying how resilience has changed over time. Regime shifts in the ecological components may be viewed as environmental crises. Such crises and other unexpected ecological events can result in dramatic changes in management. The history of water management in the Florida Everglades during the 20th century can demonstrate such dynamics. During this time at least four management regimes or eras can be identified. In the case of the Everglades, changes in management regimes can be attributed to specific events; some reflected unforeseen variation in larger scale processes (e.g. flood, storm, and drought). In other cases, environmental crises associated with ecological regime shifts also triggered major changes in management, and the creation of new eras.

> **Regime and regime shift** -*A regime is an identifiable configuration of a system, also often called a system state. A regime has characteristic structures, functions, feedbacks and therefore, identity. A regime shift is the rapid reorganization of a system from one relatively unchanging state (or regime) to another.*

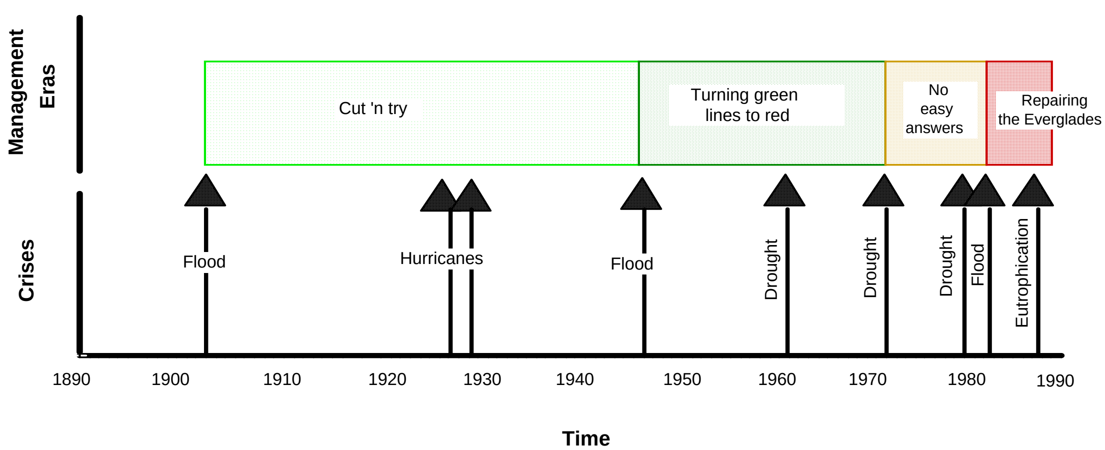

Figure 1.3.1 Five management eras in the Florida Everglades.

Initial Drainage Era (1900-1947) – Cut and try. Following a flood in 1903, canals were built to drain the wetland. This was soon followed by yet more canals to provide further drainage. In 1926 and 1928 hurricanes devastated human developments along the east coast and south of Lake Okeechobee. Earthen dams around the lake were breached during the hurricane of 1928, resulting in extensive flooding and the loss of about 2400 lives. In response to this crisis, the federal government funded the construction of the Hoover Dike around Lake Okeechobee to contain floodwaters. This era was labeled 'Cut and Try' reflecting the cutting of canals into the land and attempts to drain what was perceived as excess water.

Flood Control Era (1947-1971) – Turning green lines into red. Following a massive flood in 1947, which overwhelmed all of the previous canal systems, the state and federal governments built a large public works project to control floods. A series of levees, canals, pumps, and new management institutions were constructed to enable economic and agricultural development in previously wet areas of the wetland. The era is called 'turning green lines to red' because the plans identified new structures as green, then were colored red after construction.

Water Supply Era (1972-1983) – No easy answers. The combination of 70 years of draining the wetlands, a drought, and a growing population led to concerns over water supply. Changes in water management rules called for water conservation as well as flood protection. The state created a new system-wide management agency (The South Florida Water Management District).

Environmental Restoration Era (1984 to Present) – Repairing the Everglades. A series of environmental crises (algae blooms, unwanted vegetation changes and continuing decline in wading bird populations) in the early 1980's led to the current era - Repairing the Everglades. This era is characterized by attempts to restore ecological attributes of the system such as wading bird nesting populations, aquatic communities, and landscape vegetation patterns. The current restoration plan has a budget of 8 billion US$ and is attempting to recreate a more natural hydrologic regime and to clean polluted water while maintaining current land uses of agriculture and urban development.

Key Messages

- Social-ecological systems undergo change over time. Those changes can be slow and predictable, or they may be fast and unforeseen. These changes can result from external sources of variation interacting with internal vulnerabilities.
- Environmental crises can signal or accompany the loss of ecological resilience. They can also serve as windows of opportunity for change.
- Historical profiles can reveal how human interventions and management actions can lead to the loss of resilience.
- Historical assessments indicate how understanding, values, perceptions and priorities of the system have changed over time. These factors can also lead to regime shifts- in the ecological, social and/or economic components.

In the assessment that follows you will create a historical profile of the focal system. The timeline should distinguish among different eras or dominant themes during a particular time period (e.g., management era, development era) and illustrate, where possible, why these eras changed. It is important to determine what differentiates these time periods and what triggered change in the system, both in terms of specific management actions as well as how certain values for landscapes can drive long-term ecological impacts. The eras may be characterized by political differences, economic changes, ecological changes, or technologic changes.

Resilience Assessment

Create an historical profile of the focal system:
The development of an historical profile or timeline helps to reveal the longer-term dynamics of the system. It can help reveal the main social or ecological drivers in the system, and how change has occurred (such as episodic change through perturbations, or slow linear changes). It can also help identify the types of disturbances or shocks that have occurred, and the social and ecological responses to those shocks.

One method to creating an historical profile is to use three long pieces of paper (or a blackboard with three rows), labeling one row the focal scale, one the coarser scale, and one the finer scale. Establish the length of the history that you wish to describe (100 years, 1000 years, etc.) and appropriate unit of resolution (such as 5 or 10 years). Sketch a line on each sheet of paper that represents this time period, with appropriate subdivisions for the resolution. Mark events that are of significance to your system (e.g., social, ecological, and economic events) and put them on the appropriate scale. You can either mark on the paper directly or place post-it notes (which are easier to move around and change). At this stage it is more important to identify big events and or events that changed the management of the system.

Draw connections between related events. For instance, was a shift in agricultural production at the focal scale caused by an earlier economic shock at a larger scale? If so, indicate the reason for the connection.

For each of the events you identified above, determine if the event caused a dramatic change in the characteristics of the system. How would you characterize the system before the transition? How would you characterize the system after the transition? Give each era a name (try to identify 3-6 eras).

For each era summarize, in the table below, the event that led to a change in era (the ‘triggering event’), and list the attributes you believe made the system vulnerable to change.

Look for any patterns in the picture you have created. How often do ‘triggering events’ come from the coarser scale(s)? How often from the finer scale(s)? How often from the economic domain? The social? The ecological? In other words, what are the critical domains in your system, and is there a pattern of cross-scale interactions?

Keep a record of the timeline you have created. Devise a plan for how you will record, archive, and disseminate the results of this assessment, and make a record of any **action items**.

Table 1.3.1 Summary of historical profile of focal system

Era	Crisis or triggering event	Vulnerabilities that led to change

1.4 Resilience to What? Disturbances

Managing resilience requires managing and working with disturbance regimes. Efforts to prevent or otherwise control disturbances can inadvertently weaken a system's resilience. Disturbance regimes can also change over time requiring both an understanding of the historical pattern of disturbance and forward looking plans for adaptation.

Upon completing this section you will have:

- Documented the critical disturbances affecting your focal system in terms of their frequency and impact.
- Reported which of these disturbances have been changing in magnitude or frequency.
- Identified potential novel disturbances that could affect your focal system in the future.
- Developed a list of disturbances that are potentially threatening.

Testing Urban Resilience: New Orleans and Hurricane Katrina

Figure 1.4.1 Northwest New Orleans. Source: US Coast Guard

The city of New Orleans is situated on the Mississippi River in the southeastern United States. The city has developed around the river, and for over two centuries has been a major commercial seaport- utilizing the river as a transportation corridor that links the Midwestern US with the rest of the world. The economic and social development of the city has been based on controlling the river.

Because of flood control and water management in the Mississippi River basin, the sediment supply that once replenished the soils of the delta is moved out to the Gulf of Mexico. The lack of sediment input, combined with soil subsidence, has led to many parts of the city now being below sea level.

Floods can occur from high rainfall over the drainage basin or from storm surges associated with tropical cyclones. At such a precariously low elevation, the city is protected from flooding by a system of levees and canals. This system of defense was built in a piecemeal fashion over time as successive governments invested in infrastructure to control floods. Structures and operations were added in response to flood events that revealed the inadequacy of the system to control natural variability. According to the federal agency that builds and manages the flood-control system, the systems resilience was overwhelmed in 2005 by Hurricane Katrina.

Hurricane Katrina moved inland from the Gulf of Mexico in August 2005 and passed over the city. The accompanying storm surge raised water levels in the surrounding open waters. A number of levees failed because the hydraulic pressure from the high water caused part of the substrate in the levees to slip, resulting in levee failure. Nearly 80% of the city was inundated, with some areas lying 4 meters under water for weeks following the storm.

Fifty levee breaches were recorded, and much of the levee system needs to be rebuilt. Losses are estimated at greater than 20 billion US$. More than 1,200 lives were lost. The population of the city decreased by one-third, as many moved away and didn't return. Economic impacts persist, as oil and gas production facilities were shut down or damaged. The federal government, which takes a lead role in disaster relief, was seen as slow to react and incompetent. The myth of flood protection by the federal agency was shattered. Wide spread looting and anarchy occurred after the storm, as law enforcement was non-existent and informal networks were unable to maintain order.

Hurricanes and floods are two types of ecological disturbances. Both are disturbances that originate from processes that occur at larger scales. Hurricanes are self-organized systems that disperse heat from the tropics to the temperate regions of the globe, and as such can be described at spatial scales of a hemisphere. Yet, at the scale of cities, these cyclonic storms cause massive disruption through intense winds, surges, and rainfall. Hurricanes such as Katrina have hit coastal Louisiana before, and will do so in the future. As such, accumulated observations can be used to develop statistical estimates of how often a type of storm will hit a given area. Four major hurricanes have affected New Orleans during the 20th century.

Key Messages

- A disturbance can generally be thought of as anything that causes a disruption to a system. Disturbances in ecological systems can be such things as drought, fire, disease, or hurricanes. Disturbances in economic systems can come as recessions, innovations, or currency fluctuations, for example. Disturbances in social systems can include revolutions, new fashions, new values, or technological changes.

- Disturbances can be characterized in many ways—by their frequency, duration, severity, or predictability, to name just a few.

- Human intervention in an ecological system may also be considered a disturbance. Humans visit novel disturbances on ecological systems, such as the application of fertilizer, or the building of roads. As populations and consumption levels grow, human disturbances can intensify, with consequences for resilience.

- It is important to consider the suite of disturbances affecting a system. A previously benign disturbance might have much greater consequences if it follows another disturbance from which the system hasn't had a chance to recover.

- Systems that have been 'protected' from disturbance may not have the capacity to cope in the absence of such protection.

- Management strategies that strive to overly control disturbances (e.g., by reducing variability) can erode the resilience of the managed system, making it susceptible to even small disturbance events.

In the following assessment you will characterize the disturbances in your focal system and some of the impacts of those disturbances. The next few chapters go into more detail on thresholds, after which you will return to disturbances to assess the threshold(s) towards which they may be pushing the system.

Resilience Assessment

Consider the full suite of disturbances (from ecological, social, and economic domains) currently or historically affecting your focal system. Consider both 'pulse' and 'press' disturbances - pulse disturbances being events that occur and then cease before recurring (e.g. plowing, hurricanes, disease outbreaks) while press disturbances are unremitting (for instance, a grazing land that is stocked year round). Identify disturbances that have in the past fundamentally altered the nature of your system or its trajectory, such as those 'triggering events' you identified in the timeline activity. Enter them in the table below, and identify their attributes.

Consider known or potential disturbances that may affect your focal system in the future. Enter those in the table below, along with their attributes.

Which of these disturbances appear most threatening to the valued attributes of your focal system? In other words, which might have the capacity to introduce a severe 'shock' to the system? (This initial assessment will be a 'best guess' or 'expert opinion'—we will revisit the role of disturbance in later chapters.) These are frequently disturbances that are changing in magnitude or intensity over time, indicating new challenges to the system.

Note that efforts to increase resilience of some system regime to a specified set of disturbances can unwittingly reduce the resilience of the system to other, non-specified (yet to be experienced) disturbances. This raises the issue of the need to maintain general resilience while engaged in necessary efforts to enhance specified resilience to known threats and disturbances.

Consider the disturbances identified above. Which of these are actively managed, or suppressed? Is there any reason to believe that there is too much suppression of any of the disturbances—in other words, that by overly protecting the system (be it ecological or human) you are making it less resilient and more vulnerable to unmanaged disturbances? Should any of these management strategies be reconsidered? Record any **action items**.

After completing this first part of the assessment, re-visit and consider whether you are still comfortable with the definition of earlier attributes (i.e. focal system boundaries, multiple scales, and historical timeline).

Table 1.4.1 Summary table of focal system disturbances

Disturbance	Pulse or Press?	Frequencies of occurrence (if pulse)?	Does the system have time to recover between occurrences (if pulse)?	Variable or component of the system most affected? (e.g., soil, markets, etc.)	Magnitude of impact (minor to severe)	Change in the past few years or decades? (none, little, less frequent, more intense, etc.)
Future						

2 Assessing and Managing Alternate States and Thresholds

2.1 Alternate States

2.2 Thresholds

2.3 Scenarios

In this section you will assess possible alternate states of your system and the processes or disturbances that could cause the system to shift form one state to another. Many systems have the potential to exist in more than one state and often one particular state is more desirable than another, such as clear versus cloudy lakes. Understanding the possible alternate states of a system and the processes that move the system toward a threshold or tipping point can guide the management of natural resource systems. You will also consider plausible future scenarios for your system as a way of exploring different directions of change in your system.

2.1 Alternate States

Managing resilience requires understanding the potential alternate states in your system and the processes involved in changing from one state to another. Some systems can exhibit a lot of variation over days, months, years etc. but an alternate state is distinguished by a different structure or composition of organisms and a change in the processes that reinforce a particular state. One can draw on past experiences and future projections to consider possible alternate system states. When looking at the processes underlying a change of state, it is important to pay attention to social, economic, *and* ecological domains.

Upon completing this section, you will have:

- Identified possible alternate states for your system.
- Summarized the ecological, economic, and social characteristics of each possible alternate state.
- Attempted to define the desirability of each alternate state based on the norms and values of different stakeholders.
- Identified the processes and disturbances that might move your system from one state to another.
- Devised a plan for formulating a scientifically-based dynamic model of possible alternate states of your focal system.

Grass and woody states of savannas

Savanna ecosystems are found around the world in areas of low to moderate rainfall. They are characterized by sparse tree cover and a rich, diverse ground cover of grasses and forbs.

For thousands of years, humans have used savanna systems for livestock production, primarily cattle or sheep. In many cases humans can control the amount of grazing that occurs, ranging from a few animals per unit area to many. The level of grazing (or grazing pressure) can lead to dramatic changes in the dominant type of vegetation (e.g. shrubs and trees versus grasses).

The savanna system can exist in different configurations - measured by the relative amount of grasses and shrubs. If there are more grasses, the system is considered to be in a grass-dominated state (Figure 2.1.1). This state may persist for long periods of time with recurring fires, even with grazing. Hence it is a stable (or quasi-stable) state. Other states, such as a shrub-dominated state can also exist (Figure 2.1.2). These states and the transition between them are controlled primarily by interactions between grazing pressure and fires.

Figure 2.1.1 Grass-dominated state of savanna in Northern Australia

Figure 2.1.2 Shrub-dominated state of savanna in Northern Australia

In the grassy state, the balance of grass and shrubs is maintained by frequent fires and a relatively low grazing pressure. As more animals are added to the pasture, more of the grasses which fuel the fires are removed. The removal of fuel and changes in its spatial pattern limits the system's capacity to carry a fire. In the absence of regular fire events, more woody shrubs become established. The shrubs inhibit grass growth and do not carry a fire. Thus the shrub-dominated state of this system can persist for decades and may only return to a grass regime through direct manipulation of woody vegetation. Note that the woody state of savanna systems no longer provides the grazing benefits of the grass-dominated state. Hence the woody state is not as desirable for continued livestock production.

Alternate states are identified by a shift in dominant organisms or system structure and a change in the processes that reinforce a particular state. In particular, they are identified by a change in the nature or intensity of feedbacks in the system. For the savanna example the change in feedback has to do with the feedback from the amount of grass to the intensity of fire. The alternate regimes are characterized by dominance of grasses, or shrubs. Alternate states do not only exist in the ecological communities, as shown in the savanna example. In chapter 1, an exercise was undertaken to identify historical eras or periods. These different periods represent alternative configurations or regimes (or states) in the social or ecological components of these managed systems. In some systems it may be desirable to transform the system into an alternate regime.

Alternate state - *identified by a shift in dominant organisms or system structure and a change in the processes that reinforce a particular state.*

Feedback – *a signal within a system that loops back to control the system. In natural systems feedback can help to maintain stability in a system (negative feedback) or it can speed up processes and change within the system (positive feedback).*

Stable state – *a system with stability. Stability being the ability of a system to return to an equilibrium state after a temporary disturbance. The more rapidly it returns, and with the least fluctuation, the more stable it is.*

Transformability – *the capacity to create a fundamentally new system when ecological, economic, or social (including political) conditions make the existing system untenable.*

Transformation – *a change that results in a*

Key Messages

- Many systems show consistent traits over long periods of time. Grasses and sparse trees characterize savanna ecosystems. Coral reefs are characterized by diverse coral colonies and communities of fish.

- The existence of these long-term and persistent characteristics led scientists to recognize a phenomenon known as 'stable states'. 'Stable' in this sense doesn't imply unchanging. There is usually some level of variation while the overall characteristics of the system remain largely the same. The assemblage of fish species in a freshwater system may change with time but the system remains more or less the same. Similarly, politicians can come and go, while the form of government remains unchanged.

- Some systems may have only one stable state. A disturbance might temporarily move the system away from the stable state, but once the disturbance passes, the system will return to its normal state. For example, if a grassy savanna had only the stable state of being grass-dominated, cattle grazing might reduce the grass biomass, but once cattle were removed, the grass would recover its original levels.

- For many complex systems there are likely to be two or more *alternate states.* Savannas can be mostly grassy or mostly woody; coral reefs can be dominated by corals and fishes or be covered in algae; lakes may be clear or cloudy with algal blooms.

- Some system states are difficult, bordering on impossible to change. These are highly resilient states, though they may not necessarily be desirable states.

- The challenge is to make desirable states more resilient, undesirable states less resilient, and to recognize that thresholds separate alternate states.

In the assessment that follows you will attempt to define potential alternate states for your system and the processes that might move your system from one state to another. Drawing on both historical events and future projections, you will explore the potential for alternate states in your focal system. At this stage it is not necessary to know (and may never be possible) to know the exact position of thresholds between states. Consider social and economic states as well as ecological ones. That is, in some systems, alternate ecological states can trigger state changes in the human dimensions of a system.

Resilience Assessment

Suggest and define possible or probable alternate states for your focal system. Considering the history of the system may help in identifying likely alternate states. It might also be helpful to think about the range of conditions seen in other similar systems. Another approach might be to consider different visions or scenarios for the future of the system (see chapter 5 for more on scenarios). Past management assessments and modeling efforts may also have identified alternate system states. These states may be primarily in the ecological realm and/or the social realm.

Briefly summarize the ecological, economic, and social characteristics of each possible alternate state.

Attempt to define the desirability of each of the states listed above based on the norms and values of different stakeholders. Indicate whether participants agree on desirability of states. If there is no agreement, what are the sources of these differences? How would you go about resolving these differences?

Often it is useful to graphically depict system states and the processes that influence the transitions among states. Two such examples are given below. The first is a state-and-transition model for a semi-arid rangeland system. The boxes define four alternate states (including a transitory state labeled II in the diagram) and the arrows indicate transitions (T) among the states.

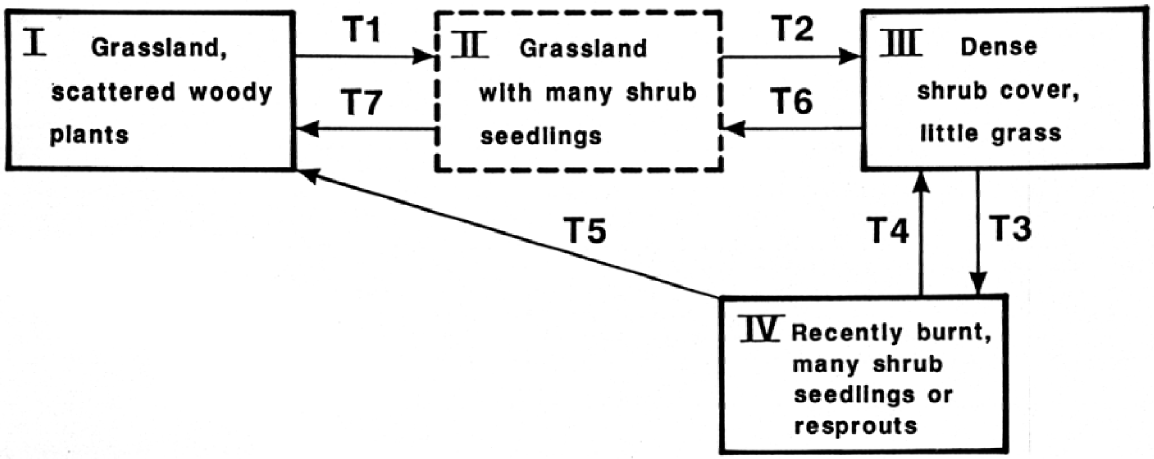

Figure 2.1.3 State and transition diagram for a savanna system.

Draw a diagram of the type in Figure 2.1.3 for your focal system, depicting alternate states as boxes. Label each box and possible transitions among the boxes. For each transition, describe the ecological, social, or economic process that influences the transition. For instance, in the savanna example used earlier, we consider how grazing could move a savanna system from a grassy to a woody state. Note that there may be more than one arrow between states, and some processes may appear more than once (e.g. grazing may be important both in moving the system from state A to state B, and from state B to state C). A more thorough consideration of factors or events that might trigger changes in state will be covered in the next section.

A second example of a state and transition model, this time for a sylvo-pastoral system is shown in Figure 2.1.4. This model below was used in a role-playing game to help managers decide on appropriate actions. It identifies different states of the system that have different consequences for people, and the natural and human drivers of the transitions between states.

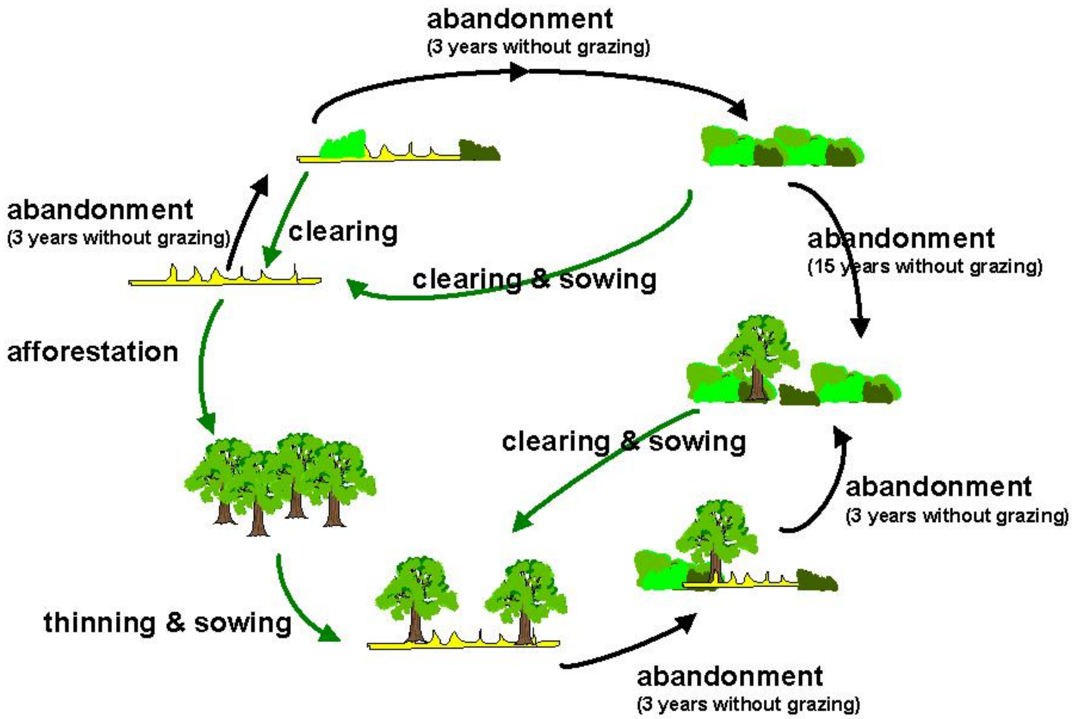

Figure 2.1.4 A State-and-Transition model for a sylvo-pastoral system (from Etienne 2003, Figure 5).

Models of alternate states and the pathways between them can be valuable tools for managing for resilience. Developing a conceptual model also brings to the forefront an individual's or group's existing mental model(s) and can facilitate a process of synthesizing diverse perspectives. Have there been past efforts to model alternate states of your focal system and the processes that would move your focal system from one state to the next? If not, or if these efforts have been inadequate or incomplete, identify local scientists and/or modelers (from both the ecological and social sciences) who might help in devising future dynamic models of alternate states. Develop a plan for engaging them either in this process or in subsequent processes. Make a record of any **action items**.

2.2 Thresholds

Managing resilience requires identifying and managing the critical thresholds that separate desirable states from undesirable states. Knowing the factors that push a system beyond a threshold may be more important than knowing the threshold per se. Once a threshold has been crossed it may be difficult or even impossible to return to a previous state. Thus it is important to understand what it is that moves a system closer to a threshold both if it is to be avoided but also if transformation of the system is a management objective.

Upon completing this section you will have:

- Considered and possibly identified critical thresholds in your system.
- Determined what factors, including potential disturbances, might be pushing your system closer to critical thresholds.
- Developed a list of system attributes that underpin changes in slowly-changing variables, system drivers that can strongly influence the position of thresholds in the system.
- Devised a plan for further understanding and managing critical thresholds and disturbances in your system.

Lakes, Agriculture, and Thresholds

Phosphorus is a common element that is necessary for plant growth and is often added to agricultural fields in order to increase the yield of crops. During and after rainfall, some of that phosphorus is carried in runoff to surrounding areas including wetlands and lakes. The added phosphorus then nourishes plant and algae growth in the lake. Over time with continuous phosphorus inputs from field runoff, the phosphorus accumulates in mud sediments at the bottom of lakes.

The amount (concentration) of phosphorus in the lake-bottom sediments is a key factor in determining whether the lake tends to be clear with green plants on the bottom (one state) or murky with algae blooms (alternate state).

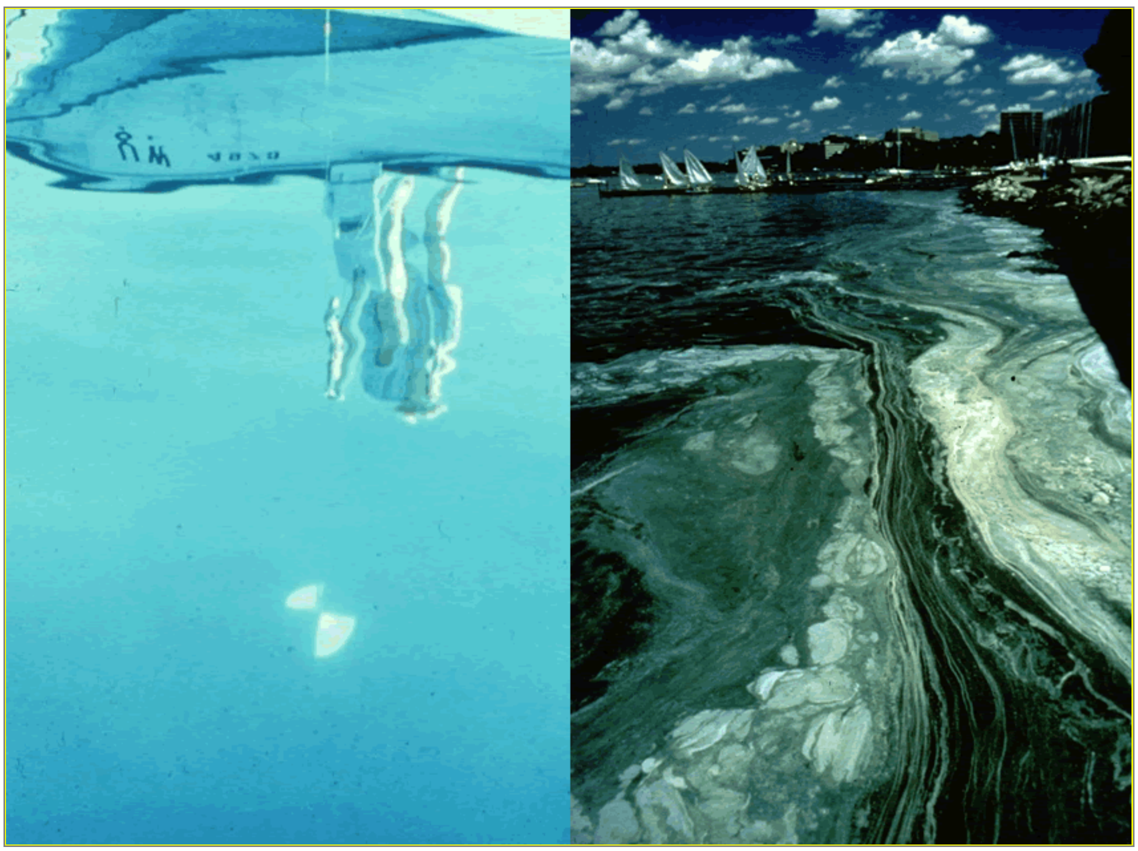

Figure 2.2.1 Both images are Lake Mendota, Wisconsin. In the image on the left the lake water is clear, in the image on the right the water is murky with algal blooms. Source: Center for Limnology, University of Wisconsin.

The dynamics of the phosphorus nutrient cycle are complex, as are the factors that trigger a transition between clear water and cloudy water (algal) states. Scientists have found that the amount of phosphorus in the sediments is the key factor that defines the threshold between the clear and murky water states. The speed at which sediment phosphorus concentration changes is slower than the rate of phosphorus input, or the speed at which algal blooms occur, and as such is called a slow variable. In this case, as in other examples where resilience is lost, the threshold is associated with components that change more slowly than other parts of the system.

A century ago, human sewage was usually funneled into lakes. This also increased the levels of nutrients in the sediments of these water bodies. Eventually, the process of eutrophication led to declines in water quality and shifts in lake state. Even with the construction of water treatment plants, which were designed to remove phosphorus from sewage, many lakes have not returned to their original clear-water state. In some systems, once thresholds have been crossed, it is difficult (if not impossible) to return to the previous state.

> **Eutrophication** – *is the enhanced growth of vegetation or phytoplankton that causes algal blooms in aquatic systems, resulting from high concentrations of compounds such as nitrogen and phosphorus.*

Key Messages

- A threshold has been crossed when feedbacks change, and consequently the defining characteristics of the system change, leading to an alternate system state.

- One might consider different configurations or alternate states of a system based on the history of the system, the range of conditions seen in similar systems, or by way of different visions for the future of the system (see 2.2 Alternate States).

- Some changes in system state are difficult or impossible to reverse. It is not always possible to restore lake clarity for example, by simply reducing phosphorus levels to what they were before the threshold was crossed. The threshold that triggers a change from clear to cloudy lake may not be the same threshold that will trigger change from a cloudy to clear lake.

- Thresholds can also move. In general, we often find that it is the slowly-changing variables in a system that cause a shift in the position of thresholds. Phosphorus input levels that a clear lake could absorb in the past, may suddenly trigger change to a cloudy lake. In this case, phosphorus bound up in lake sediments is released, changing the lake's tolerance to the amount of external phosphorus inputs.

- Thresholds, sometimes referred to as tipping points, exist in social and economic systems as well. In the United States, for example, public intolerance

> **Tipping point –** *the moment of dramatic, rapid change, such as with the rapid rise or fall of an epidemic.*

to second-hand-smoke from cigarettes reached a certain critical level and smoking rapidly moved from being publicly acceptable to being unacceptable.

- Managing for resilience requires being aware of thresholds, determining what its characteristics might be, favorably altering the position of thresholds where possible, and keeping systems away from thresholds that lead to undesirable states.

In the following assessment you will identify potentially critical thresholds in your system and explore which disturbances might be pushing your system closer to these thresholds. It is not essential to know the exact position of thresholds – which is rare, and they shift in any case. You will also look at slowly-changing variables in the system, which often strongly influence the position of thresholds in the system.

Resilience Assessment

Return to the alternate states diagram you developed in the previous section. True alternate (as opposed to transient, intermediate) states are separated by thresholds. Consider each of the processes you identified as having the potential to move the system from one state to another. Attempt to identify which of the transitions are smooth and gradual and which of the transitions are abrupt and jumpy. For example, the transition in a rangeland as it shifts from being grass-dominated to shrub-dominated passes a threshold level of woody biomass beyond which the feedback to fire intensity changes, and the system then goes all the way to a woody state even if all livestock are removed. The change in the system's directional *dynamics* is certainly sudden, at that point, but the change in amounts of observable variables (grasses and shrubs) is gradual. In contrast, when a lake ecosystem passes the threshold in phosphate content that determines the shift from the clear to eutrophic regime, the change in dynamics of the system is sudden, and so is the change in the observable variables (algae biomass, turbidity).

Looking at the transitions, identify the cases for which reversal to the previous state are difficult. Such transitions may represent critical thresholds in the system. Can you determine the approximate position of the threshold? For some processes this may be easy—it is either 'on' or 'off' (for instance, one process may be the implementation of a policy of subsidies—once the policy is enacted, the threshold has been crossed). For others it may be difficult or impossible to determine a threshold position. Assign a value, or a range of values, to thresholds wherever you can. On your state and transition model(s), indicate the threshold value and the degree of reversibility (easily reversible e.g., a step function, somewhat reversible, or highly irreversible).

Describe any additional characteristics of the threshold(s) of potential concern.

Does the focal system appear to be near or approaching any of the thresholds of potential concern? If so, which ones? Start a list of **thresholds of potential concern**.

Do any of the thresholds lead to undesirable system states? Do any of them lead to more desirable system states? Include on the list of thresholds of potential concern whether the alternate state is more/less desirable and how reversible the transition appears to be.

Consider the suite of disturbances you identified earlier (section 1.4). Do any of these disturbances move you closer to a threshold? Are these disturbances—either singly or combined, changing in such a way that crossing a threshold is becoming more likely? Which thresholds? Are they somewhat irreversible, and do they separate the current state of the focal system from a less desirable state? Add these thresholds to the list of thresholds of potential concern. Add the disturbances that might push the focal system over one of these thresholds to a list of **disturbances of potential concern.**

Thresholds of potential concern	Disturbances of potential concern

Consider again the thresholds separating your current system state from less desirable states. List the factors or processes that might gradually be altering the position of those thresholds over time, if any (not all thresholds will necessarily move)? How manageable are these influencing factors? Note that these factors or processes are often related to **slow variables** in the system (e.g., such as phosphorus in lake sediment from the lake example). ? If possible, try to identify any slowly-changing variables that appear to be system drivers.

Factors or slow variables shifting thresholds

Consider the list of thresholds of potential concern. What management strategies, if any, can be employed to move you further away from those thresholds? What does this mean for strategic management in your focal system? Enter any **action items** on the sheets provided.

Consider the list of disturbances of potential concern. Which disturbances, if any, can be managed so that they are less likely to push the focal system over an undesirable threshold, or closer to a threshold leading to a more desirable state? (Keep in mind that trying to tightly control some disturbances can erode resilience in the system.) What does this mean for strategic management in your focal system? We will return to this section and utilize the information gathered here again in chapter 5 when considering management interventions. Enter any **action items** on the sheets provided.

Consider the factors, or system attributes, that influence the position of thresholds on the controlling (slow) variables**.** Are these attributes and their effects on thresholds adequately known and are the changes in controlling variables monitored? If not, devise a plan for monitoring them. The list of system attributes that underpin the changes in slow variables is a very important outcome of this resilience assessment, since it is these attributes that need to be managed in order to influence the changes in slow variables. Enter any **action items** on the sheets provided.

Are there any thresholds or disturbances of potential concern for which you have too little information? If so, devise a plan for obtaining further information—e.g., either through accessing historic data or modeling the system. Enter any **action items** on the sheets provided.

2.3 Scenarios

Managing resilience involves considering the future. Complicated issues such as regional development or climate change are especially challenging because future change in dynamic social-ecological systems can be largely unpredictable. A number of approaches have been developed to tackle these problems, but for the complexities of social-ecological systems, two are particularly appropriate. One is the development of system models, as was suggested earlier in this book, which can be used to help understand non-linear dynamics. Another approach is the development of scenarios. Scenarios are carefully constructed stories about the future, which include descriptions, events, actors (people), and mechanisms. They are descriptive models or representations about possible alternative paths that a social-ecological system might take.

Upon completing this section, you will have:

- Considered the multiple values of developing future scenarios and what can be learned and achieved during the process.
- Developed (coarsely) three to four plausible, alternative future scenarios for your system.
- Considered what indicators would be worth monitoring to determine if the system is following a particular trajectory to a future scenario.

Northern Highlands Lake District

Northern Wisconsin contains a high density of lakes in the landscape and a fairly low density of human habitations. In relatively close proximity to major metropolitan areas, the region attracts many tourists, who come primarily to fish. Increasing numbers of homes built around the lakes, along with increased tourism have altered the lake ecosystems. The people in this system include full- and part-time residents, visitors, and Native Americans. All of whom alter aspects of the ecosystems, through for example, fishing, changing land use, polluting the water, and introduction of non-native species. These activities influence fish populations by modifying habitats, toxics and food base. A number of global or external factors influence the system, including: climate change, regional demographics and economics, and mercury deposition. In an exercise designed to assist with planning and management of the area, a set of scenarios was developed about future development in the area (see http://www.ecologyandsociety.org/vol7/iss3/art1/). Three of these scenarios of alternative futures were: Walleye Commons, Northwoods.com, and Lake Mosaic.

> **Scenario** – *A scenario is a story that describes a possible future, by identifying significant events, actors and mechanisms. A set of scenarios that bracket the range of possible futures is a useful tool for examining the kinds of processes and dynamics that could lead to a SES developing along particular trajectories.*

Walleye Commons
In this scenario, climate change led to a warmer environment, greatly decreasing winter tourism. The warmer climate in turn led to emergent pathogens in fish and humans. These diseases made the areas much less desirable (tourists also had other options) which led to a decline in human population. The drop in land value led to purchase by government and non-government groups for conservation. Even so, mercury pollution increased as a result of global warming, leading to health risks associated with consuming fish such as walleye. Native Americans stayed, and developed strategies for harvesting walleye from the clearer, but more disease infected waters.

Northwoods.com
The northwoods.com scenario is based on a new University in the area that attracts young people to a low cost, high quality lifestyle. Economic opportunities led to increased human populations, and eventually urbanization resulting in the degradation of aquatic ecosystems. Increased pollution and nutrients caused lakes to become eutrophic, which was followed by a decline in fish stocks. Local policies were implemented to control pollution, but they were both costly and unpopular. The region continued to develop economically, which benefited Native Americans and sustained population growth in the area.

Lake Mosaic
In the Lake Mosaic scenario there was an increasingly wealthy population, as many aging baby boomers purchased lake homes for vacations or retirement. Lakeshore development exploded and all of the lakes supported homes. Homeowners

organized around their lake to improve conditions for fishing, habitat and recreation. Yet different lake associations wanted different things; some groups wanted more protection of ecological services, others wanted more use. In this scenario, private groups, rather than governments controlled development.

None of these scenarios are predictions about the future, but rather ways of helping to understand aspects of system dynamics by imagining a range of plausible futures and the processes that lead to them. Through being involved in their development the stakeholders involved gained an understanding of how different, broad directions of change might be avoided or encouraged. In qualitative terms, thresholds and alternative regimes are identified through the scenario-building process. Also, building the scenarios was a very useful collaboration technique that helped to build trust and social capital.

Threshold – a breakpoint between two regimes or states of a system.

Key Messages

- Scenarios are constructed stories about alternative futures.
- Scenarios can help develop collective action by engaging participants who systematically discuss and analyze alternative perspectives about the future.
- Scenarios can help highlight and understand uncertainties and assumptions.
- Building scenarios can help increase the general resilience of the system by identifying potential shocks and previously unconsidered thresholds and alternative regimes. As well as by increasing connectivity and trust in the social system.

Scenario Development

Using the information developed in chapter 1, gather together the following information: the key actors in the focal system; key ecological, economic, and social components; and external system drivers.

Sketch out three to four plausible, alternative future system states or trajectories. Ideally, each of these represents alternative system configurations or regimes. Some of these future states may be explored more fully in the next section.

For each of the future regimes, describe the mechanisms and processes that would lead to that regime. What surprises (i.e. changes in focal configuration, or in external drivers) would lead to one or more of these future states?

What indicators would you track to know which, if any, of the trajectories might be currently on-track?

3 Assessing and Managing Cycles of Change

3.1 Cycles of Change: The Adaptive Cycle

3.2 Cross-Scale Interactions: Influences from Below and Above

In this chapter you will use a very general model of system dynamics (the adaptive cycle) to assess patterns of change in a focal system and explore how influences from systems at finer and coarser scales influence a system's resilience. You will also begin to formulate a plan for managing cycles of change and cross-scale interactions.

3.1 Cycles of Change: The Adaptive Cycle

Managing resilience requires understanding cycles of change and the vulnerabilities and windows of opportunity these cycles of change introduce. The adaptive cycle (Figure 3.1.1) describes four phases of change (growth, conservation, release, and reorganization) that are characteristic of many systems, particularly natural resource systems. Having an understanding of where a system is in the adaptive cycle as well as knowing a bit about past cycles of change in the system allows for more strategic management. Whether your goal is to reduce the risk of crossing an imminent threshold or to change the system's trajectory in order to make it more sustainable, knowing how system vulnerabilities and opportunities vary from phase to phase can help to guide management decisions.

Upon completing this section you will have:

- Identified which of the four phases of the adaptive cycle your focal system is currently in.
- Distinguished past adaptive cycles in your focal system.
- Determined which disturbances and vulnerabilities appear to trigger movement through the four phases of the adaptive cycle.
- Formulated management strategies for fostering innovation, maintaining critical capital, and allowing flexibility in the focal system.

Forest Fires - an ecological example of the adaptive cycle

Forest fires provide an example of a system that undergoes adaptive cycles. Fires occur in cycles that are characterized by gradual changes and abrupt transitions. Those transitions occur following disturbances- in this case fire is the disturbance. Forest ecosystems develop gradually in a process of succession. Forest succession begins usually with bare ground that is colonized by fast growing grasses and shrubs. Since early succession species are selected for fast growth and rapid reproduction, this is called the 'r' phase of succession, which corresponds to the 'growth' phase of the adaptive cycle (Figure 3.1.1).

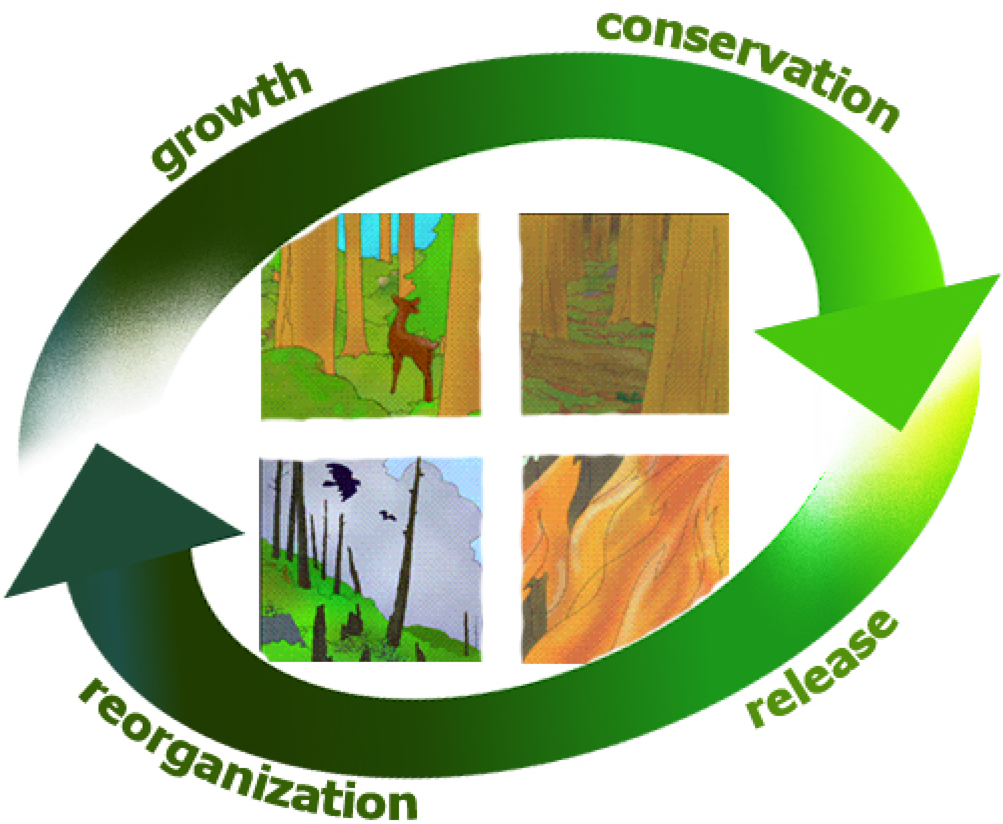

Figure 3.1.1 The Adaptive Cycle and forest renewal through fire and succession. The growth phase and conservation phases are commonly described as forest succession. Fires can be viewed as disturbances, or as an agent of creative destruction by which accumulated structure is released. Fires are quickly followed by a renewal or reorganization phase in which new seeds, remnant vegetation and other mechanisms lead to a new growth phase.

Over time scales of decades to centuries, the system matures as forest structure (biomass) increases. However, that structure doesn't increase forever, due in part to the way in which energy is used in the system. As systems mature and structure increases, the energy captured by that system goes into maintaining the accumulated structure, as a result the system loses some flexibility and capacity to adapt and respond to change. The system doesn't keep growing, but tends to reach limits (only so many trees can grow in a given space and trees can only get so big) or a state in which the system is slowly changing (a steady state). Once a system approaches a steady state or carrying capacity, it is referred to in ecology as the 'K' phase, also called the 'conservation' phase of the adaptive cycle (Figure 3.1.1).

The biomass that has accumulated in late-succession forests becomes vulnerable to disturbances, such as fire. The amount of biomass or fuel in a patch, and connections among patches across the forest are necessary ingredients for fires (along with some ignition source and appropriate weather conditions). Once there is sufficient fuel combined with dry conditions and a spark, fires can destroy all or part of the existing forest structure. This is the 'release' phase, also called 'creative destruction'.

Following a fire, the system can reorganize as the system is colonized by different species. The seed bank in forest soil is a form of natural capital that allows the regeneration of certain plant species. In other types of systems various forms of capital (e.g., natural capital, financial capital, infrastructure, human capital such as education, and social capacity such as trust and networks) that are built up during the growth and conservation phase, are critical in determining the system's resilience and adaptability.

The alpha (or beginning) phase sets the stage for subsequent succession and development phase. This entire sequence is called an adaptive cycle.

United States Telephone Industry - Organizational Dynamics

The patterns of the adaptive cycle apply to systems other than ecological ones. Some authors have represented business cycles in the context of phases of the adaptive cycle, while others have demonstrated these patterns for institutional dynamics. One example is from the US telephone industry during the 19^{th} and 20^{th} centuries and involves the Bell System.   This industry exhibited at least three cycles, each of which was driven by significant restructuring events followed by periods of reorganization and maturation.

The first such cycle followed the expiration of original patents in the late 1890's. As the patents expired, so did the monopoly held by one company. The expiration of patents was an omega event and led to a reformation of the strategy and actions including attempts to limit competition, to prohibit connections to new companies, and to expand its own network, among other actions.

The second cycle occurred with the advent of new leadership and a new strategy in 1907. Unable to stem the new companies, the Bell System began acquiring other companies in order to maintain dominance in the business.

The third cycle began in the early 1920's, when the Bell system became a regulated monopoly. This structure persisted for over six decades until the early 1980's. This period was characterized by increasing normalization of business, selection of managers and leaders from within and a focus on operations aimed at maintaining the regulated monopoly. The advent of new technology tested the resilience of the old system during the 1970's. A small group of users who generated most of the revenue were seeking cheaper access through the new technology. This led to a lawsuit and ultimately a court ordered break-up of the Bell System in 1982. Growing rigidity and inability to adapt are cited as reasons for dissolving the regulated monopoly. Recent developments of digital and wireless technologies lead to the most recent phase of the industry. The restructuring events are periods of creative destruction, which led to reorganization of the Bell System. Growing rigidities and loss of adaptive capacity made the system vulnerable to these events, which resulted in new and different states of the company.

Key Messages

- Most systems are not static they are dynamic and change over time. While not entirely predictable, these changes often follow a pattern in which four phases of change are commonly observed.

- During the growth phase when resources are plentiful, fast-growing entities that can take advantage of these resources tend to dominate the system.

- As the system matures, it enters a conservation phase where resources become 'locked up' in longer-lived entities, (e.g., nutrients in the soil are absorbed by trees) and are no longer available for new colonizers. As a few species or organizations come to dominate in the conservation phase, the system tends to become less flexible which increases the likelihood of collapse.

- A release phase is often viewed as a disturbance to the system. Disturbances can destroy structure and other forms of capital, whether it is natural capital, such as accumulated biomass in a forest, or social capital such as policies or relationships, as suggested by the history of the telephone industry. These forms of capital have accumulated during the prior growth and conservation phases.

- The release phase is quickly followed by the reorganization phase during which new entities and innovations may enter the system but only a few will survive through to the start of the next growth phase.

- Often the new adaptive cycle will be very similar to the old; at other times, it will be very different. Forests may re-colonize with similar species and assemblages.

- The combined growth and conservation phases are called the 'fore loop', while the release and reorganization phases are together called the 'back loop' to distinguish system behaviour before and after disturbances.

- The system needn't move sequentially between the four phases of the adaptive cycle, other transitions are possible. Nonetheless, these four phases seem to capture the behavior, structures, and characteristics of many systems.

- Sometimes, a release phase is beneficial at the focal scale. It can invite innovation and provide a 'window of opportunity' for creating a new system configuration when the old one is untenable.

- Levels of various capitals (e.g., natural, financial, social, etc. see Appendix B) can be the limiting factor in determining a system's adaptability.

In the assessment that follows you will identify the current phase of your focal system, describe some of its past adaptive cycles and the events that appear to have triggered shifts between phases. Note that phases are not precisely defined—some people may assign a system to the growth phase while others assign the conservation phase, particularly if the system is close to a transition. Some disagreement about phase assignments should not be unexpected. Similarly, not all systems will exhibit these four-phase characteristics. If you have worked through the assessment on thresholds and disturbances (chapter 2), you may find you can deal with some of the following questions quite quickly.

Resilience Assessment

Consider which phase of the adaptive cycle your focal system (the social-ecological system) is in (**growth, conservation**, **release**, or **reorganization)**. You may wish to initially consider the different domains separately—ecological, social, and economic. What phase is each of these in? What does this mean for the overall phase of the system? (Note that some domains could, for instance, be in a growth phase but you could still determine that the overall connected system still behaves as if it were in a conservation phase.) How long have each of the domains been in their current phase? How long has the whole focal system been in its current phase? Some of this information might be gleaned from the earlier timeline activity.

Domain	**Current Phase**	**(Approximate) Length of current phase**
Ecological		
Economic		
Social		
Focal (overall) System		

For the focal system, list the dominant characteristics that have led you to assign its current phase. Does the system appear to be close to changing into another phase? If yes, what current dynamics or situations lead you to that conclusion?

Using the information that you developed in the timeline activity, can you identify past adaptive cycles for your focal system? How long did each last? Did those cycles conform to the basic sequence of change in the adaptive cycle or did they appear to follow a different trajectory? If so, what trajectory?

What crisis or disturbance (review the list of disturbances developed previously) appeared to trigger the move from the fore loop to the back loop? Note that the disturbance could come in the ecological, social, and/or economic domain. What structures or characteristics of the system made it vulnerable to that crisis or event? (In other words, why wasn't the crisis absorbed without triggering a back loop?) Was the next adaptive cycle very similar to, somewhat similar to, or very different from the previous one? If different, how was it different? If it is the same, what does that say about the back loop in terms of thresholds? [Note: Refer to the timeline and threshold assessments.]

Past Cycles (Name)	**Dominant Characteristics**	**Length of Adaptive Cycle**	**What triggered a release or shift?**	**What are the system vulnerabilities?**	**What characteristics changed among cycles?**

Implications for Management

One of the insights from evaluating many case studies in resilience is that innovation and learning *must* be fostered regardless of the phase of the adaptive cycle. Consider your assessment of the system from chapter 1. What were the sources of innovation and learning you identified? Are these retained through all phases of the adaptive cycle? Are different strategies required to promote them in different stages of the adaptive cycle? Should you consider promoting more innovation and learning—for example, retaining the innovators even when things appear to be going smoothly?

In the front loop (growth and conservation phases), efficiency is often achieved at the expense of flexibility. This trade-off is often required to achieve a conservation phase, where resources can be efficiently exploited. If too much flexibility is lost, however, systems cannot respond to surprise and are vulnerable to entering a back loop. How much flexibility—in the social, economic, and ecological domains—have you retained in your system? Is there a reasonable balance between flexibility and efficiency? If not, how can balance be reintroduced? Enter any **action items** on the sheets provided.

In the back loop (release and reorganization phases), it is critical to retain capital—ecological capital, economic capital, and social capital (e.g., human resources, trust, social networks, etc.). This capital will be required in the next adaptive cycle; if too much capital is lost during a back loop, systems risk moving into very different (less desired) states in the next adaptive cycle, or remaining in the back loop. What plans are in place, if any, to retain critical capital during periods of change and reorganization? Is more needed? Enter any **action items** on the sheets provided.

3.2 Cross-Scale Interactions: Influences from Below and Above

Managing resilience at a particular focal scale requires understanding how the focal system interacts with larger scale systems in which it is embedded as well as with the smaller scale systems of which it is comprised. Knowing which phase(s) of the adaptive cycle these connected systems are presently in can help guide management to reduce vulnerabilities in the focal system caused by system dynamics at other scales. Management actions targeted at larger scale systems to foster memory can help the focal system to retain valued components following disturbance events. Alternatively, when changing the system is the goal, then efforts to break constraints imposed by systems at larger scales may be most effective.

Upon completing this section you will have:

- Identified the adaptive cycle phase(s) of systems below and above the focal system.
- Identified the vulnerabilities to the focal scale that arise from system dynamics at finer scales.
- Identified management strategies for reducing the vulnerabilities that come from finer scales.
- Devised management strategies to capture the benefits of innovation at finer scales.
- Identified both desirable and undesirable influences from larger scale systems.
- Identified management strategies for fostering desirable influences and mitigating undesirable influences from larger scale systems.

Interactions across scales - Forest Fires

Forest fires don’t happen every year in the same place. While fires may burn different areas during the same year, the same patch of ground doesn’t generally re-burn, hence ecologists define fire frequency or return intervals of fires. That interval is related to different processes operating at different time scales.

The complexities of forest fire dynamics can seem overwhelming, but can be simplified into a few factors. One factor is the amount of fuel on the ground. This is usually equivalent to the amount of standing vegetation or biomass. Another factor is the spatial distribution of that fuel. In order for fire to spread, burnable material (fuel) must be in close proximity. A third factor involves how easily the fuel can be ignited. Dry spells with little or no rain allow fires to burn more readily because the fuel is drier and easier to ignite. The final key factor is ignition, which provides the spark to start a fire. Ignition usually comes from lightning or from the hands of humans. Each of these factors changes over different time intervals. Perhaps the quickest is ignition (milliseconds for lightning). Fuels accumulate over years. Many grasslands require one to three years for sufficient plant growth to carry a fire; forests an order of magnitude more time. Droughts can occur on at least two time scales; an annual one (such as monsoonal precipitation with wet seasons and dry seasons) and a multi-decadal cycle.

Fires occur when the following set of conditions prevail: sufficient fuel loads, fuels that are connected across an area, dry conditions that foster combustion, and an ignition source. This convergence of conditions can be described as a cross-scale interaction. Ignitions operate on a short-time scale, the process of plant growth occurs over years, fuel loads and drought cycles occur on longer-time scales, on the order of decades. Similarly, ignitions are local, plant growth is local, fuel loads can spread fires across large areas, and droughts cover large areas. The panarchy model (Figure 3.2.1) represents the dynamic interaction among hierarchically arranged levels of a system.

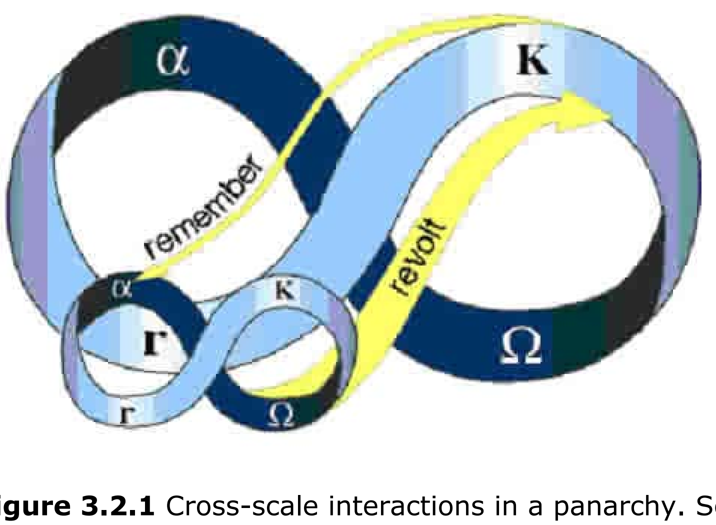

Figure 3.2.1 Cross-scale interactions in a panarchy. Source: Gunderson and Holling 2002.

Panarchy - *a model of linked, hierarchically arranged adaptive cycles that represents the cross-scale dynamic interactions among the levels of a system and considers the interplay between change and persistence.*

Plants grow and fuel loads accumulate over time. Yet the speed at which they move from an r to K phase in the adaptive cycle differ. It is the accumulation of individual plant growth over a larger area that determines the fuel load for a fire. In other words, the aggregation of smaller-scale entities (plants that burn) generates the release or 'creative destruction' at the scale of a patch or forest. This cross-scale interaction, as the smaller, faster variables in a system coalesce to create a disturbance (fire) at the larger scale is referred to as a revolt.

Processes and structures at even larger scales than the fire influence post-fire recovery. Many fire-adapted plants have seeds that are stored in cones for years and then released following a fire. Those seeds reflect years of plant growth, not to mention years of evolutionary pressure. At larger spatial scales, seeds from unburned areas colonize the burned areas during the back loop phase. Dispersed by wind, birds, and other organisms, this influx of resources is critical for post-disturbance re-colonization. Since the seeds are developed prior to the disturbance, they are considered part of the system's memory. Memory (e.g., resources) at larger scales is critical to the back loop of the focal scale. Infusions of capital in the form of seeds and nutrients in a forest are crucial for post-fire recovery. In the social and economic domains, property insurance (a form of memory), low interest loans, and recovery funds are critical to the recovery from natural disasters such as hurricane Katrina.

Key Messages

- A system at a particular scale will usually be comprised of smaller sub-systems as well as being nested itself within larger systems.
- Systems interact across multiple scales (see section 1.2) with processes occurring at one scale influencing system dynamics at other scales. This nested set of interacting systems represented by adaptive cycles—from small to large—is referred to as a Panarchy.
- The resilience of a focal system is in large part determined by the interaction of systems across this Panarchy.
- Smaller-scale sub-systems can enhance resilience of the focal system by introducing innovation and novelty to counteract inflexibility at the focal scale.
- Smaller-scale sub-systems can reduce resilience in the focal system if they are very tightly linked, i.e., in similar phases of the adaptive cycle. In such a

case, disturbance can rapidly spread across scales, creating a cascading collapse of systems.

- Historically, management of natural resources had a tendency to suppress adaptive cycles at smaller scales, thus reducing the resilience of the focal scale. For instance, for a long time the fire policy in the U.S. was to suppress all fires, even small-scale fires. This resulted in forest patches of similar age (similar phase in the adaptive cycle), so that after a period of time, freshly ignited fires spread much more rapidly, threatening the larger forest. Allowing fires at smaller scales maintains a forest mosaic with stands of different ages, which helps to contain fires and prevent more massive events.

- Larger scale systems can help provide the 'memory' that allows the next adaptive cycle to be similar to the current one.

- Memory can be a positive thing when it allows us to retain valued resources, traditions, norms, and interactions.

- Memory is not necessarily always a good thing. At times it may be desirable to enter a new adaptive cycle and this may require breaking the constraints from above to allow room for innovation and change.

- Innovation and change may require loosening the connections between the focal scale and the larger scales and cultivating tolerance for new and alternative ideas, resources, and other sources of novelty.

In the assessment that follows you will identify the current adaptive cycle phases of the finer-scale subsystems of your focal system in order to detect vulnerabilities and consider management options for addressing such vulnerabilities. You will also assess the relationship between the focal scale and larger scales, identifying the positive and negative aspects of that relationship and devising management strategies to enhance the positive aspects and diminish the negative ones.

Resilience Assessment

Consult the table of sub-systems and super-systems you completed in section 1.2. What phases of the adaptive cycle are your finer scale sub-systems in? Note that a focal scale will be made up of several sub-systems at each finer scale. For example, if the focal scale is a particular watershed, the finer scale would be the sub-catchment scale, but many sub-catchments make up the larger watershed. Similarly, the focal scale may be a city, the finer scale the neighborhood, but the city is made up of several neighborhoods Are each of these sub-systems at the finer scale(s) in a similar phase of the adaptive cycle, or different phases? How does this pattern depend on domain (social, economic, and ecological)?

Are the innovations and learning that come from back loops at the finer scales being captured at the focal scale? If not, what mechanisms can be put into place for capturing this innovation and learning, and incorporating needed flexibility at the focal scale? Enter any **action items** on the sheets provided.

What phase of the adaptive cycle do the larger-scale systems (i.e. larger than your focal-scale system) appear to be in?

What are the main larger-scale influences on your focal system? Does memory exist mostly in the ecological, economic and/or social domains?

Consider the past adaptive cycles you identified in section 3.1. How many new adaptive cycles replicate older ones? What sources of memory might have been acting in the system then?

Considering the phases of the adaptive cycle in which you find your focal system and the larger-scale systems, in what ways do the larger-scale systems (in both ecological and social components) constrain the focal system? How have inputs from larger-scale systems fostered change or resisted change in your focal system?

As an initial assessment, would you say there is a good balance between flexibility and efficiency in your focal system? In other words, is your focal system likely to avoid moving into a late 'conservation' phase?

What management strategies are needed, if any, to enhance memory from larger scales or reduce constraints? (Consider all the domains – ecological, social, and economic.) Enter any **action items** on the sheets provided.

Is your focal system in a conservation phase? Are the finer scale sub-systems also in a conservation phase? If both the focal system and sub-systems are all in a conservation phase, then there is an increased risk of disturbance cascading across scales. Are conditions such that you may want to create large-scale change in your focal system?

If the nested set of systems is aligned in the conservation phase, but large-scale change is to be avoided, what management strategies might help break this alignment? What costs or challenges might come from breaking this alignment? Can you put into place programs to minimize the costs, or make them tolerable? Enter any **action items** on the sheets provided.

Note that the alignment of systems (i.e. nested systems in the same adaptive cycle phase) cannot always be readily broken, in which case action should be taken to prepare for a back loop (release and reorganization). Enter any **action items** on the sheets provided.

If the constraints from the larger-scale system are too stringent, are there individuals or organizations that you can approach to discuss how to weaken these constraints in order to build resilience and flexibility? Who are those individuals and organizations? What materials would be needed to begin the dialog. Devise a plan for interacting with these people. Enter any **action items** on the sheets provided.

4 Adaptability and Transformative Change

In this section you will evaluate the adaptability of the focal system. How adaptable a system is relates to the capacity of people to manage ecological resilience. People can increase the adaptability of a system by building capital. Sometimes it is desirable to transform the system, into some other kind of system, and set it on a new trajectory. In this section you will consider whether the system can or should be transformed, and what are the sources of natural and social capital needed for transformation?

Managing resilience requires adaptability – the ability to monitor, assess, respond, recover and renew following known and unknown disturbances and other change. An adaptable system is able to maintain or manage ecological resilience. Sometimes transformation or fundamental change of the system is required. Such transformation relies on the development and nurturing of different forms of capital in order to create and implement options for managing a system.

Upon completing this section, you will have:

- Identified individuals or organizations that have key leadership roles.
- Characterized the relationships, trust, and ways that the various stakeholders work together.
- Examined the capacity of the system to respond to change.
- Identified governance attributes and institutions (both formal and informal) in your system.
- Identified various forms of capital in the system and devised a plan to build capital where it is needed.

Building Social Capital to Transform Management of Kristianstad Vattenrike, Sweden

Figure 4.1 Kristianstad Vattenrike, Sweden. Photo: Sven-Erik Magnusson

Kristianstad Vattenrike is a social-ecological system in southern Sweden. It is comprised of wetlands, lakes, rivers and forests around the town of Kristianstad. The ecosystem provides services such as flood control, habitat, biodiversity, as well as cultural and recreational opportunities. In the late 1980's wading-bird populations were in decline, eutrophication of lakes and wetlands was occurring, and traditional uses of the wetlands for haymaking and grazing were becoming increasingly marginalized. Despite international recognition of the wetland, many people viewed the system as something of a wasteland or 'poor' system and feared imminent crisis. Under the leadership of a key individual, the system was transformed under a new management system that helped to change people's perception of the system to one in which the water and landscape was a source of wealth or richness (the Swedish word *Vattenrike* can be roughly translated into two English meanings; either water realm or water rich). That transformation was achieved by four interacting processes: 1) integrating knowledge, 2) developing a vision and goals within a common framework, 3) development of a robust social network, and 4) recognizing and acting when a window of opportunity opened.

Great leaps in understanding were gained by integrating existing knowledge. Inventories and maps of economic and cultural resources in meadows and pastures were combined with information on natural values such as habitats and unique biota. Further integration occurred when it was realized that maintaining the status quo of protection would not reverse declines in bird populations. All of which led to the creation of an eco-museum, which became the hub of transformation activities.

A common vision was needed to bring together a diverse set of land uses and management practices. This vision was fostered by a small group of actors, each in different organizations with different goals. They developed goals for the eco-museum, which would focus on environmental protection, conservation, tourism and education.

A social network evolved to discuss and develop proposals to carry out the new vision and goals. The network developed a proposal that addressed social, economic and ecological aspects for new management approaches. The discussions garnered a broad base of support for the eco-museum proposal. That support crossed scales and sectors, from farmers to bird watchers and from the municipality to county and national interests.

A window of opportunity opened for the eco-museum at the local political level and led to a major transformation in the management of the system. This was enabled by a set of factors, including a) a desire to 'put Kristianstad on the map', b) receptivity of a local politician c) economic opportunities - the new museum would provide potential for recreation and ecotourism, and d) an explicit statement by the nation of the importance of environmental issues.

Key Messages

- The capacity of people, individually and collectively, to manage ecological resilience is adaptability.

- By building capital and trust, the people and organizations involved in a social-ecological system can transform systems.

- Capital has many forms (e.g., economic, cultural, human, natural, political, and social). It is important to distinguish among the various types of capital present in any given system and to understand which types of capital most need to be enhanced and what trade-offs might be involved when different forms of capital are at odds with each other.

- Social capital can be increased when the management of the resource system engages stakeholders at all levels of governance from local to international institutions.

> **Institutions –** *Rules and norms that guide how people within societies live, work, and interact. Formal institutions are codified rules such as the constitution, organized markets, or property rights. Informal institutions are rules governed by social or behavioral norms of a family, community or society.*

- Building adaptive capacity through the development of trust and capital can be done by:
  - investments to secure ecosystem goods and services;
  - incorporating ecological knowledge into institutional structures;
  - creating new social and ecological networks;
  - combining different forms of knowledge for learning;
  - providing incentives for stakeholder participation;

   - identifying and addressing knowledge gaps; and developing expertise to address those gaps.

- Trade-offs can exist among different forms of resilience. Efforts to increase the resilience of a system to a specified set of disturbances can sometimes reduce the resilience of that system to other disturbances. These trade-offs should be identified.

- Adaptive governance can add to adaptability of social-ecological systems. It does so by integrating different types of understanding with adaptive forms of resource management through formal and informal institutions to learn and respond.

- Adaptive governance can enhance general resilience by encouraging flexibility, inclusiveness, diversity, and innovation.

> **Adaptive governance –** *institutional and political frameworks designed to adapt to changing relationships between society and ecosystems in ways that sustain ecosystem services; expands the focus from adaptive management of ecosystems to address the broader social contexts that enable ecosystem-based management.*

In the assessment that follows you will characterize and assess the various mechanisms for enhancing capital in our system. This will be done by identifying leaders, examining the role of stakeholders and evaluating social capacity in the system. You will also assess system adaptability by examining the roles of governance and institutions in your system and look for opportunities to enhance adaptability.

Resilience Assessment

Is transformation of the system desirable or necessary? What obstacles can you identify to transforming the system? How might you get around those obstacles?

Identify individuals or organizations that have key leadership roles. Are there mechanisms in place to develop leaders and leadership skills?

How would you characterize the levels of 'trust' among key stakeholders in the system?

Do stakeholders at all levels of governance have a say in the management of the system? What mechanisms are in place for gathering and incorporating input from stakeholders into the management of the system?

How would you describe the capacity of the community to respond to crisis or disturbance? What limits this capacity?

Which forms of capital present in the system most need to be enhanced?

What is the role of social networks in the system? Do they tend to be dynamic or restrictive i.e. are existing social networks perceived as beneficial to the system or do they impede opportunity for change and innovation?

How is knowledge-sharing among stakeholders facilitated? Is the process of knowledge-sharing formalized or institutionalized in any manner?

Consider the following list of examples for building capital and trust – are any of these practices occurring in the system?

-strategic investments to secure ecosystem goods and services
-incorporating ecological knowledge into institutional structures
-creating social and ecological networks
-combining different forms of knowledge for learning
-providing incentives for stakeholder participation
-identifying and addressing knowledge gaps
-developing expertise

Is the system being managed for enhanced resilience to specific threats? If so, does this focus on a specific aspect of the system strengthen or challenge the system's overall general resilience?

What institutions (formal and informal) are important in regards to resource use in the system? How flexible are these institutions? Is innovation, encouraged in these institutions? If not, how might this be changed?

Identify trust-building opportunities in your system and devise a plan for implementation.

Devise a plan for improving knowledge-sharing among stakeholders and formalizing mechanisms for input from all levels of governance.

Try to define what is known and what is not known about the main management issues in your system. Make explicit any assumptions underlying these issues.

5 Next Steps: Interventions and management

5.1 Interventions

5.2 Adaptive Assessment and Management

In this section we explore where and how to intervene in the system in order to enhance (or where necessary reduce) resilience. This part of the resilience assessment is completely context-dependent and so precludes any sort of prescriptive, recipe approach. What is offered here are approaches to help consider what can be done, or what steps can be taken, including the development of new approaches to policy or management based on what has been learned in the previous chapters of the resilience assessment.

5.1 Interventions

Managing resilience involves knowing when, where, and how to intervene. It involves managing interventions holistically, by considering how multiple interventions might interact with each other and carefully planning the sequencing of actions. Single interventions or 'quick fixes' usually offer only partial solutions and are rarely successful over the long-term.

Upon completing this section, you will have:

- Devised a list of high-priority interventions based on thresholds of concern.
- Explored the potential effects of specific interventions across multiple scales.
- Considered the type and timing of interventions in the context of adaptive cycle and panarchy dynamics.

Grand Canyon interventions

In section 1.1, the Grand Canyon was introduced as an example of the types of issues faced by practitioners in assessing and managing around issues of resilience. The construction of the Glen Canyon dam in the 1960's dramatically changed the ecology of the river. In resilience terms, the dam created a physical regime shift. Prior to the dam, highly variable flows, temperature and sediments characterized the river. Indeed the name Colorado loosely translates to 'blushing', suggestive of a color change from blue or green to red. Since the dam, the river is characterized as a clear, cold river with highly controlled flows.

Over the past two decades, managers of the Colorado River ecosystem in the canyon have focused on attempting to return the system to more desirable ecological regimes. Desired conditions include the development of habitats that increase and sustain populations of currently endangered native fish species, restoring the sediment inputs to the river, and return of a seasonal temperature regime. These objectives have been pursued through an adaptive management program (see section 5.2). The management program conducted two large-scale flow experiments, one in 1996, the other in 2004. The experiments consisted of the release of large volumes of water from the Glen Canyon dam. In conducting these experimental releases, scientists have developed a better understanding of sediment dynamics, as well as hydrodynamics. The managers have also conducted predator control experiments, to increase recruitment of endangered native fish populations. This approach was enabled by a social system that has evolved in response to attempts at resolving complex issues.

In 1997, the US Secretary of the Interior developed a new management program for the Grand Canyon that was aimed at integrating and organizing the actors to develop different ways of intervention. That management program came about because of a crisis that recognized existing institutions were not the best way to meet objectives. Prior management structure of river system was characterized by a complex maze of different government agencies, environmental laws and stakeholders all of which focused on the operation of the Glen Canyon dam. The primary institution for resolving disputes over desired goals in the river system (natives versus non-native fish, amount of sediments, among others) and how to best meet those goals was the court of law. That is, when agency actions were not agreeable to stakeholders, then stakeholders would sue agencies to meet their demands. These cases would result in long delays in decision-making, and ultimately courts would turn back to agencies, because of the technically challenging nature of solutions. As an alternative, a program was established that included stakeholders such as fishermen, rafters, electrical power utilities, conservation groups, among others. This program is called the Glen Canyon Adaptive Management program. The program focuses on means of collaboration around an approach called adaptive management (as described in section 5.2).

Key Messages

- Management interventions for resilience are aimed at two strategies: 1) enhancing system resilience in order to maintain a desirable regime and 2) transforming the system into a new or very different state.

- The key to transformation is the development of new approaches, new mental models, or the reframing of issues.

- Crises and disturbances can provide an opportunity for transformation. Droughts or floods, for example, can reveal that existing policies or management actions are no longer working and should be changed.

- Interventions can be targeted at different components of the social-ecological system and might include:
    1. changing or creating new policies and institutions – modifying regulations, property rights, rules, norms, standards;
    2. fiscal capital and monetary mechanisms, such as investments subsidies, taxes, markets, other economic instruments; and
    3. manipulating ecological goods and services, for example by creating or removing dams along rivers, controlling fish harvests, or restoring wetlands.

In the following section you will draw on the information gathered in the assessment sections of previous chapters to explore a set of system interventions with the ultimate aim being to build resilience in a sustainable natural resource system so that it can continue to provide goods and services over the long term.

Intervention Considerations

Management goals
Do existing management goals suggest maintaining the current ecological state or changing to a new one? Do existing management goals focus on increasing the resilience of the current state? If so how?

List any planned interventions or suggested interventions from the resilience assessment in previous chapters (review your list of ***action items***).

Thresholds
Consult the resilience assessment in section 2.2 and review the list of thresholds of potential concern and identify the critical thresholds that constitute priority attentions for intervention. Next review the list of factors/slow variables affecting these thresholds. These factors are what policy and management need to focus on.

Refer to the list of interventions developed above and add/remove suggested interventions as necessary.

Scale

The institutions or other entities involved in making interventions operate at different scales and it is helpful to consider possible interventions at multiple scales. Considering the list of priority interventions, iterate between scales to explore how the intervention might affect or be affected by processes or interventions at other scales. Use the information summarized in Table 1.2.1 (Multiple scale characteristics linked to the focal system) to help you explore the possible cross-scale interactive effects of proposed interventions.

Adaptive cycle & panarchy

The kinds of interventions that are most appropriate (and inappropriate) are influenced by the phase of the adaptive cycle. Referring back to section 3.1, if the focal system is in a fore loop (growth or conservation phase of the adaptive cycle), consider two common fore-loop trends that may require intervention: 1) Becoming too good at it, i.e. not recognizing that increases in efficiency of production are reducing response diversity. Maximizing production through increased efficiency often leads to unwanted surprises – e.g., collapsed fish stocks, epidemics; 2) Becoming increasingly reluctant to change from what has developed into a successful production system.

If the focal system is in a late-conservation phase, there may be strong resistance to change. One option is to induce small disturbances, to force the release of resources and re-organization, before it happens through a potentially large, external disturbance. The aim in fore loop intervention is to either bring about a move back along the axis from conservation to growth phases, or to induce a small-scale back loop that quickly re-sets the system into a rejuvenated growth phase without significant loss of capital.

Another way to think about this is to identify sub-systems of the focal scale (identified in section 1.2), and generate back loops or 'release and reorganization' in some of these sub-systems. A strong proposition in resilience theory is that generating back loops at small scales prevents systems at higher scales from approaching crisis and collapse.

If the focal system is in a back loop (release and reorganization phase of the adaptive cycle i.e. existing arrangements are unraveling, people and capital leaving, ecosystems 'collapsing'), the main aim is to retain as much capital as possible while fostering and speeding up the re-organization phase. Bring to an end the release phase as quickly as possible, while retaining 'memory' and resources. The trade-off from an intervention perspective, is to allow novelty to flourish as much as possible during the back loop while also constraining it so that the back loop doesn't last too long.

A common cross-scale effect that reduces resilience and that may require intervention is the provision of subsidies from higher scales to enable K-phase behavior at the focal scale to persist (help *not* to change, rather than help *to* change). Consider the interactions among institutions at different scales (identified above) and examine them in terms of needed changes that may call for intervention. In terms of panarchy behavior, what cross-scale interventions are called for?

Considering the set of priority interventions identified above, are there any sequencing issues involved in implementing the interventions? Obvious ones would be ensuring appropriate changes in regulations are in place before recommending management changes, but there may be less apparent interactions amongst the interventions. Sequencing interventions within ecological, economic and social domains, and between them, needs to be considered before any are implemented. Place the interventions into sequential order and examine the consequences, using the insights gained from the models you have developed and your understanding of panarchy effects.

5.2 Adaptive assessment and management

Managing resilience involves a knowledge-based approach to interventions. Knowing when, where, and how to intervene can be informed by an adaptive management approach that involves probing the system in an experimental way to gain understanding of system dynamics. Equally important to considering which interventions to make, is knowing what *not* to do, and knowing when to stop current activities that are harmful to the long-term sustainability of a system.

Upon completing this section, you will have:

- Considered how and why to develop and use an adaptive management approach.

Adaptive assessment and management of a sea-grass system

Florida Bay is a shallow, subtropical marine ecosystem located at the southern terminus of the Florida peninsula. For most of the 20th century, the bay had clear water and a bottom covered by sea-grass. Around 1990, the sea-grass began dying over most of the bay. The die-off was an ecological crisis, and created great political, social and economic turmoil. Since much of the bay is in Everglades National Park, the social objectives of conservation in the park were brought into question (would the grass return? what (if any) management actions led to the die-off?). Sport fishing and tourism relied on the clear water state of the bay. Since many wealthy people (including the President of the USA at that time) used the bay for recreation, the crises became instantly politicized.

The sea-grass die-off resulted in the system flipping from being a clear-water, grass-dominated system to one with muddy water and recurring algae blooms. While living, the sea-grass plants stored nutrients and the root systems stabilized the sediments. The loss of sea-grass released nutrients into the water column and allowed for the sediments to become suspended in the water column by wind-generated currents. But much wrangling and discussion went into trying to understand what caused the shift in ecological regimes.

As the first stage of adaptive assessment and management, a computer model was developed to sort through a set of hypotheses that had been proposed to explain the regime shift. These included hyper-salinity resulting from a decrease in freshwater flow and altered water circulation, an increase in nutrients from surrounding areas, a lack of hurricanes, loss of herbivores (turtles and manatees), disease and temperature stresses. The most plausible explanation involved a spatially homogenous stand of high sea-grass biomass (probably related to a lack of disturbances

Adaptive management is an approach captured in the phrase 'learning by doing'. It is a learning-based approach to resource management that views policies as guesses or hypotheses, and actions as ways of testing those guesses. The main point of an adaptive assessment is to try to define what is known and what is not known about various management issues. It makes explicit the assumptions underlying management. Management actions can then be structured to test these assumptions (system understanding), while solving management issues. In doing so, adaptive assessment attempts to fill the gap between knowledge and action.

To begin setting up an adaptive management program it is useful to summarize the alternate regimes within the focal system. And it helps to think about regimes that occur in the ecological domain, economic domain, political domain, and social domain.

It will likely be necessary to test the form and positions of identified thresholds for at least some of the regime shifts listed, and experiments of this kind involve costs, sometimes in the form of foregone profits where reduced levels of use are one of the treatments. This will be especially important in tests to determine if the system is in an undesired regime, and what it will take to restore it to a desired one. The allocation of costs is part of the intervention plan.

such as storms and grazers). The stress caused by high temperatures caused local die-offs as photosynthesis could not produce enough oxygen to keep up with respiratory demand.

Since the beds contained high biomass, the die-off spread as dead material in the water column further depressed photosynthesis. Without sea-grass, the sediments and nutrients became suspended in the water column, leading to algae blooms and muddy water. Both of these factors inhibited subsequent sea-grass establishment. Hence loss of ecological resilience (amount of disturbance that the system can absorb without changing state) was related to the slowly changing variable of sea-grass biomass. The regime change (or state change) was not related to one stressor, but to a small set of factors including sea-grass biomass, disturbance regimes and sediment stability.

An adaptive assessment process was designed to help sort among these alternative hypotheses. Note that depending on which of these might be true, management would embark on different actions. If the hypersalinity proposition were true, then managers would want to decrease salinity stress by delivering more freshwater to the bay. This is what happened, with no sign of reversing the state change. Instead, the models developed during the assessment indicated that the sea-grass biomass was at the heart of most of the explanations, the lack of disturbances contributed to an over abundance of sea-grass biomass, that that spatially homogenous, high biomass contributed to the die-off, and that the bay would likely recover to a grass dominated state. Over the past fifteen years, the models were substantially correct in describing the recovery of sea-grass. This example demonstrates that management interventions should always be robust to the key uncertainties around the loss of resilience, and that monitoring should capture the essential dynamics of the system.

Key Messages

- The core feature of adaptive assessment and management is the development of a model of some kind that attempts to integrate understanding of the system from various disciplines.

- With adaptive management the system model is used to pose questions about how the system might behave, rather than attempt to predict policy consequences. These questions are evaluated or tested over time through management actions, monitoring the results, and updating the model accordingly.

- Rather than continue a set of exercises to develop an Adaptive Assessment and Management program, the reader is encouraged to pursue the development of a program with the aid of key references provided in Appendix B.

The development of a new or critical review of an existing Adaptive Assessment and Management program is the logical next step following the completion of a resilience assessment. The results of the resilience assessment should allow the social-ecological system stakeholders to hold an informed discussion on what they need to do about the resilience of their region.

Glossary of terms

Adaptive capacity/Adaptability – the capacity to adapt and to shape change. Adaptability is the capacity of actors in a system to influence resilience. In a social-ecological system, this amounts to the capacity of humans to manage resilience. (Walker, Holling, Carpenter, and Kinzig. 2004).

Adaptive governance – institutional and political frameworks designed to adapt to changing relationships between society and ecosystems in ways that sustain ecosystem services; expands the focus from adaptive management of ecosystems to address the broader social contexts that enable ecosystem-based management (Carpenter and Folke 2006).

Alternate state - Alternate states are identified by a shift in dominant organisms or system structure and a change in the processes that reinforce a particular state.

Cross-scale - Influences between the dynamics of systems at one scale and the dyanamics of those that are embedded in it or enfold it.

Desirable and undesirable regimes – A coarse indication of collective human attitudes and expectations towards particular system configurations. An awkward term that often raises queries – but highlights a tension about the ways in which society (in general, or a particular segment) regards particular system regime in contrast to an alternative regime.

Disturbance - In ecological terms, disturbance is a relatively discrete event in time, coming from the outside, that disrupts ecosystems, communities, or populations, changes substrates and resource availability, and creates opportunities for new individuals or colonies to become established.

Eutrophication – is the enhanced growth of vegetation or phytoplankton that causes algal blooms in aquatic systems, resulting from high concentrations of compounds such as nitrogen and phosphorus.

Feedback – a signal within a system that loops back to control the system. In natural systems feedback can help to maintain stability in a system (negative feedback) or it can speed up processes and change within the system (positive feedback).

Institutions – Rules and norms that guide how people within societies live, work, and interact. Formal institutions are codified rules such as the constitution, organized markets, or property rights. Informal institutions are rules governed by social or behavioral norms of a family, community or society.

Learning and innovation - Learning involves the comparison of mental models with data and information from the world. At least two types of learning have been described: incremental and transformational. Incremental learning can occur when information and data are used to evaluate ongoing plans, models and policies. Ongoing monitoring programs can be used to evaluate whether proposed management actions are achieving desired goals. In this case, the underlying mental model or scheme is fixed. Transformational learning occurs when underlying models, schema or paradigms change. This type of learning occurs after an environmental crisis, where policy failure is undeniable. It requires innovation in the form of development of new ideas, models and policies. Transformational learning is also described as evolutionary learning where not just new models or schema are developed, but also new paradigmatic structures that lead to new sets of policies or management actions.

Panarchy - a model of linked, hierarchically arranged adaptive cycles that represents the cross-scale dynamic interactions among the levels of a system and considers the interplay between change and persistence (Holling et al 2002).

Regime and regime shift -A regime is an identifiable configuration of a system, also often called a system state. A regime has characteristic structures, functions, feedbacks and therefore, identity. A regime shift is the rapid reorganization of a system from one relatively unchanging state (or regime) to another.

Resilience – the ability of a system to absorb shocks, to avoid crossing a threshold into an alternate and possibly irreversible new state, and to regenerate after disturbance.

Scale - any measurable dimension (such as space or time). Structures can be measured in terms of spatial resolution (minimum) and extent (maximum), e.g. a farm covers 100 hectares. Processes can be resolved in similar temporal terms, e.g. a cyclone persists for 24 days. For the purposes of a resilience assessment, a focal scale of the social-ecological system of interest is usually determined from among: landscape/local scale, sub-continental/sub-regional, continental/regional, and global scale, over a specified period of time.

Scenario – A scenario is a story that describes a possible future, by identifying significant events, actors and mechanisms. A set of scenarios that bracket the range of possible futures is a useful tool for examining the kinds of processes and dynamics that could lead to a SES developing along particular trajectories.

Social-ecological system (SES) – an integrated system of ecosystems and human society with reciprocal feedback and interdependence. The concept emphasizes the 'humans-in-nature' perspective.

Stable state – A stable state refers to a system with stability. Stability being the ability of a system to return to an equilibrium state after a temporary disturbance. The more rapidly it returns, and with the least fluctuation, the more stable it is (Holling 1973).

State variable – a component in the system for which the amount of that component can be tracked or measured. State variables include items such as land, biomass, livestock, farmers, roads, etc.

Threshold – A breakpoint between two regimes of a system (Walker, B. and J. A. Meyers. 2004).

Tipping point – the moment of dramatic, rapid change, such as with the rapid rise or fall of an epidemic.

Transformability – The capacity to create a fundamentally new system when ecological, economic, or social (including politicaly) conditions make the existing system untenable.

Transformation – a change that results in a fundamentally new system.

Appendix A - Key References

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Appendix B – Different types of capital

THREE TYPES OF CAPITAL

(excerpt from: Ecological Economics, Vol. 5, No.1. Fikret Berkes and Carl Folke "A Systems Perspective on the Interrelationships Between Natural, Human-Made and Cultural Capital," pages 1-8, 1993.)

Human-made capital is capital generated via economic activity through human ingenuity and technological change; the produced means of production. This is a common definition of capital in economics textbooks.

Natural capital consists of three major components: (1) non-renewable resources such as oil and minerals that are extracted from ecosystems, (2) renewable resources such as fish, wood, and drinking water that are produced and maintained by the processes and functions of ecosystems, (3) environmental services such as maintenance of the quality of the atmosphere, climate, operation of the hydrological cycle including flood controls and drinking water supply, waste assimilation, recycling of nutrients, generation of soils, pollination of crops, provision of food from the sea, and the maintenance of a vast genetic library. These crucial services are generated and sustained by the work of ecosystems (Odum, 1975; Folke, 1991). Only through maintenance of an integrated, functional ecosystem can each environmental good and service be assured; such goods and services cannot be managed one by one as independent commodities.

Cultural capital refers to factors that provide human societies with the means and adaptations to deal with the natural environment and to actively modify it: how people view the world and the universe, or cosmology in the sense of Skolimowski (1981); environmental philosophy and ethics, including religion (Leopold, 1949; Naess, 1989); traditional ecological knowledge (Johannes, 1989); and social/political institutions (Ostrom, 1990). Cultural capital, as used here, includes the wide variety of ways in which societies interact with their environment; it includes cultural diversity (Gadgil, 1987).

For more information on capital see also : World Bank Sources of Capital webpage http://www1.worldbank.org/prem/poverty/scapital/sources/index.htm

Social Capital - Social capital refers to the aggregate of actual or potential resources that can be mobilized through social relationships and membership in social networks.

- Families: The main source of economic and social welfare for its members.
- Communities: Social interactions among neighbors, friends and groups generate social capital and the ability to work together for a common good.
- Firms: Building and sustaining efficient organizations like firms demands trust and a common sense of purpose.

- Civil Society: NGO networks provide opportunities for participation and gives voice to those who may be locked out of more formal avenues to affect change.
- Public Sector: The public sector, i.e., the state and its institutions, is central to the functioning and welfare of any society.
- Ethnicity: Ethnic ties are a clear example of how actors who share common values and culture can band together for mutual benefit.
- Gender: Social networks of impoverished women in Brazil are important for women to obtain income and other necessities.

Feedback request

Your feedback is critical to the on-going development of this workbook. Assessing and managing resilience in social-ecological systems is a relatively new endeavor and much can be learned from the application of the process described in this workbook to a variety of systems. Sharing your knowledge and experience in using this guidebook for practitioners is essential for improving both the workbook itself and more importantly, the sustainable management of natural resource systems.

Let us know how you used the workbook (e.g., workshop setting with stakeholder participation, as an individual or with a small group of managers or others etc.), what components of the workbook were most helpful and what was less helpful, if completing the resilience assessment led to changes (what kinds of changes) in your management plans.

If you have examples from your system of interest that demonstrate or challenge any of the principles of resilience management described in the workbook then we would like to include them in a developing database that will be made available online. Authors of the examples included in the database will be fully credited.

Please send all comments and examples to editor@resalliance.org.