ASSESSING RESILIENCE IN SOCIAL-ECOLOGICAL SYSTEMS

A WORKBOOK FOR SCIENTISTS

Version 1.1

DRAFT FOR TESTING AND EVALUATION

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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

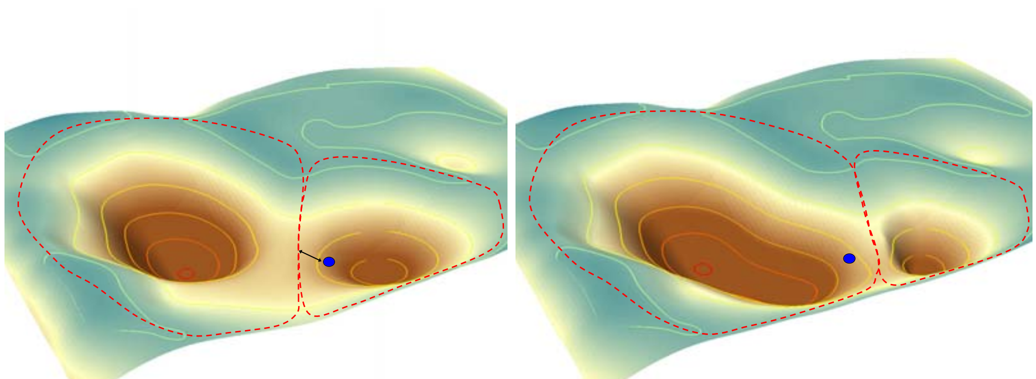
The essential feature of a social-ecological system is a multi-scale pattern (both spatial and temporal) of resource use around which humans have organised themselves in a particular social structure (distribution of people, resource management, consumption patterns, and associated norms and rules). 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.

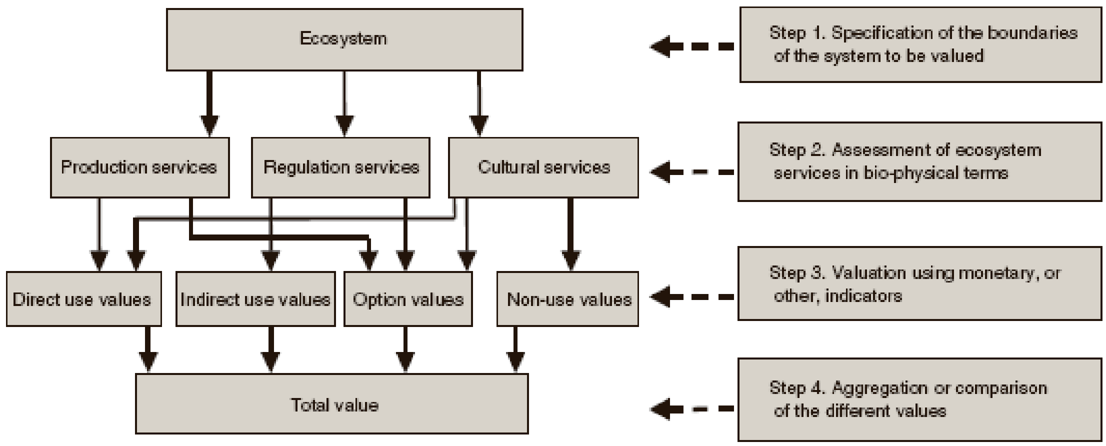


Figure 1. From Hein et al (2006) – A framework for considering the supply of ecosystem services.

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?

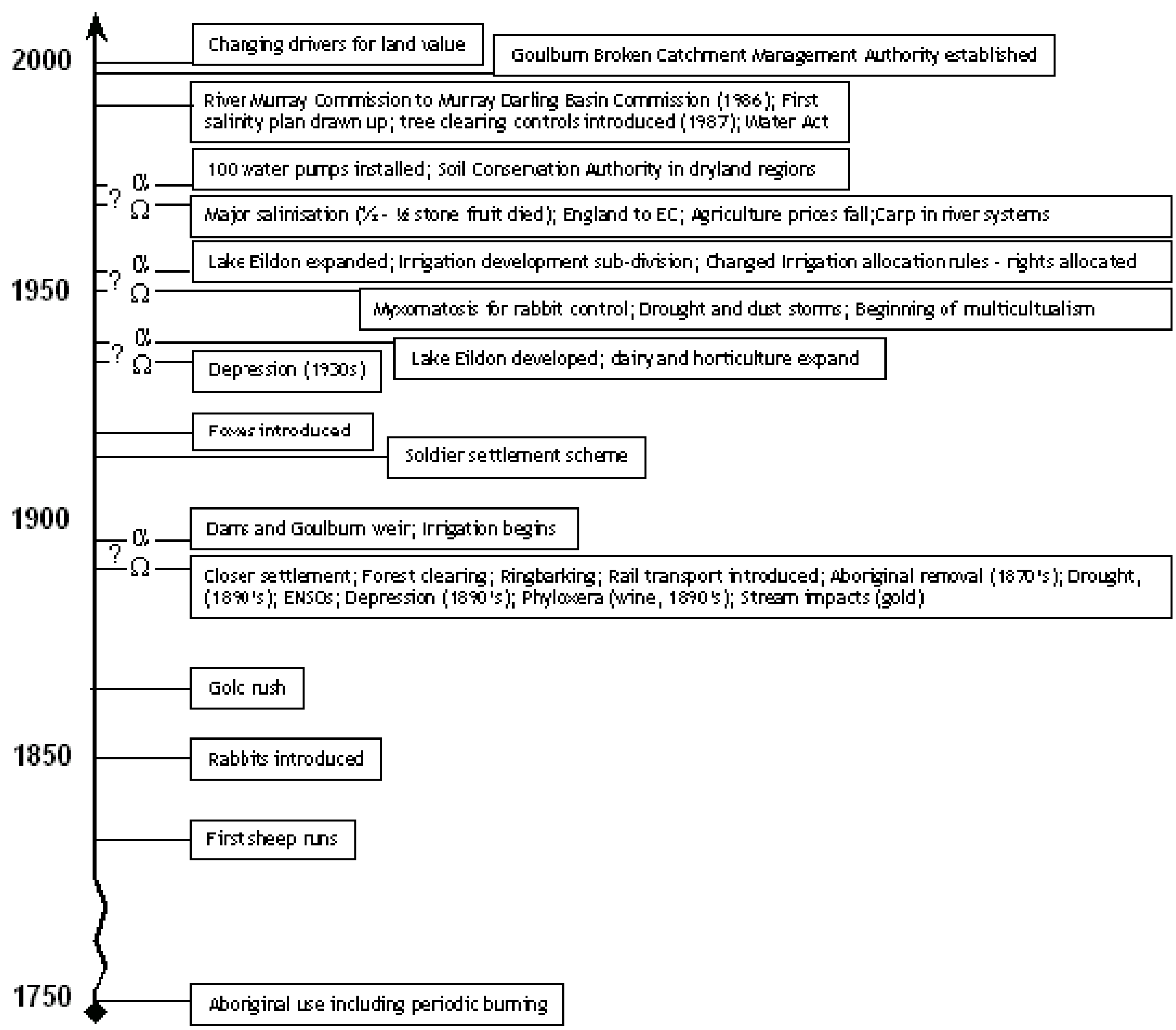


Figure 2. Historical profile of major events and developments in the Goulburn–Broken catchment. The periods with "?, α or Ω " denote times of major events or crisis, followed by reorganization. (From Walker et al 2002).

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?*

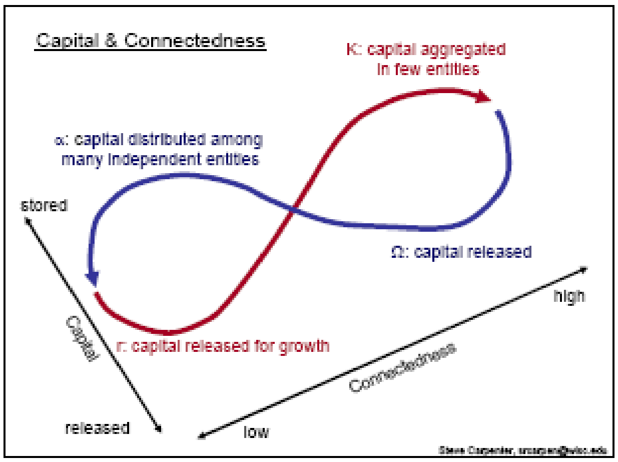
How do the mental models of social 'values' and benefits derived from ecosystem use differ? Are there clearly different attitudes to ecosystem use and the value of ecosystems to society?

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

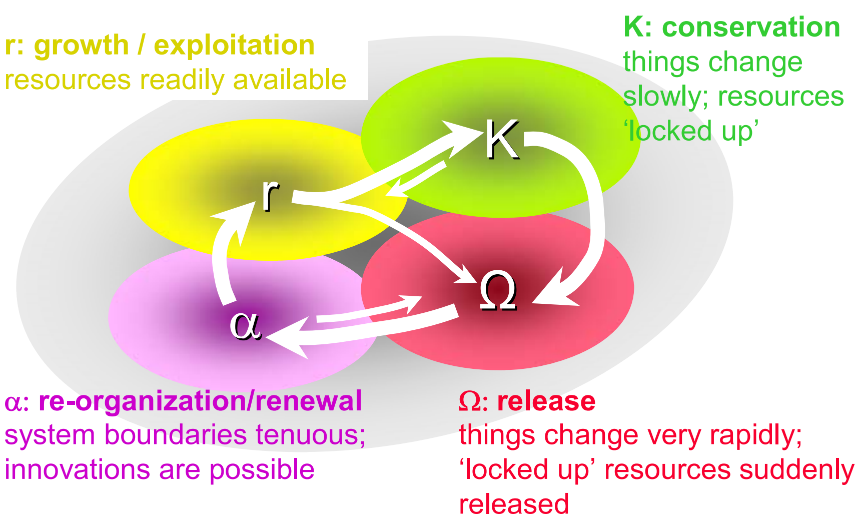
Ecosystems and social systems tend to move through different phases in their dynamics, known as adaptive cycles. Understanding which system phase can strongly influence what kinds of interventions are likely to be successful, and unsuccessful. *Does the system (at the focal scale of interest) appear 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

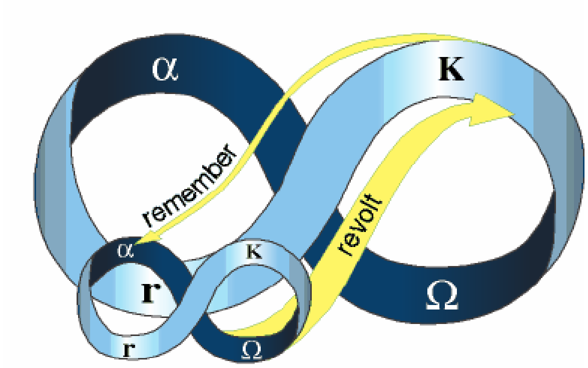
Scales and cross-scale effects

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.

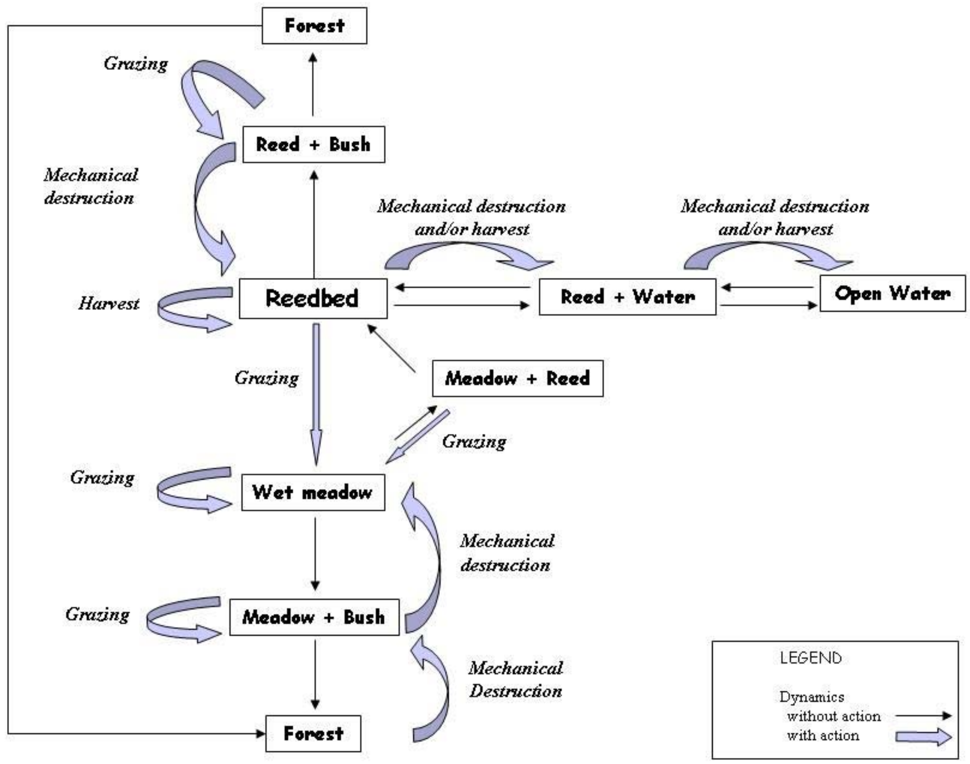


Figure 3a. State-and-Transition model of the Camargue reedbed system in the Rhone delta. Note that the boxes represent alternative states (or perhaps transitional states), and the arrows define how biotic interventions mediate the transitions among states.

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.

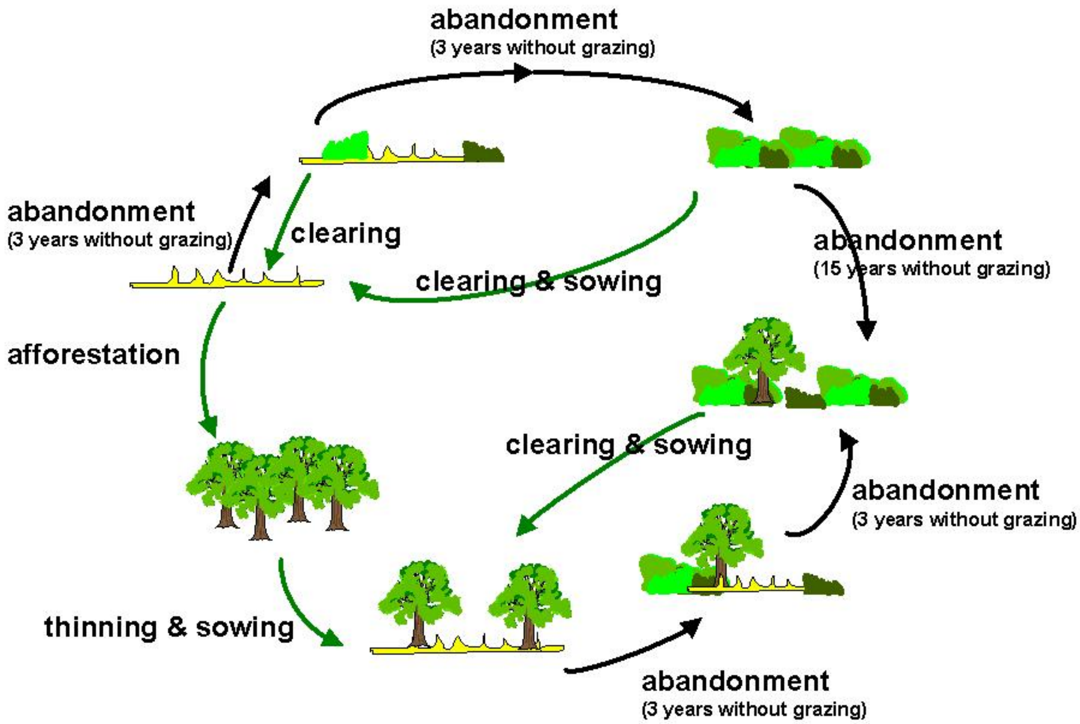


Figure 3b. A State-and-Transition model for a sylvo-pastoral system (from Etienne 2003, Figure 5).

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').

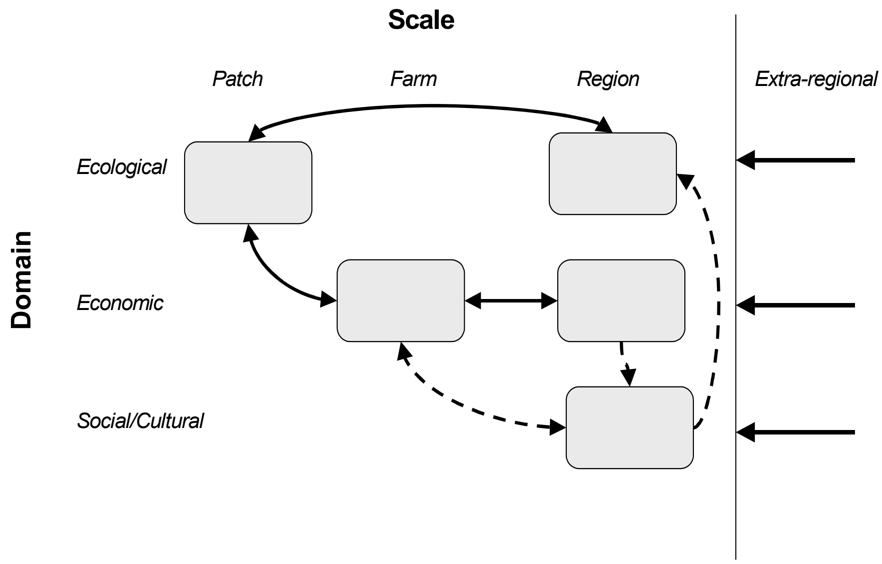


Figure 4. Multiple interacting thresholds across scales and domains (see Kinzig et al 2006). In each box, one or more thresholds were identified in each of the four regional case studies involved. Solid arrows represent threshold interactions that occurred in all four regions; for dashed arrows they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

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[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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