Assessing Resilience in Social-Ecological Systems: Workbook for Practitioners

Revised Version 2.0

Resilience Alliance

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INTRODUCTION

Human activities over the past fifty years have altered ecosystems around the world faster and more extensively than at any other time in history. These changes expose the need for a better understanding of how to manage, cope with, and adapt to change. Many of the challenges that confront natural resource management today are linked to dynamic processes that are themselves undergoing change. These circumstances require not only that we rethink how we approach human-environment interactions in the broadest sense, but also how we intervene in and manage the ecosystems upon which human well-being depends.

Traditional command-and-control approaches to managing ecosystems that assume a static model of the environment can make a system more vulnerable by masking critical system properties that may go unnoticed until it's too late. Similarly, solutions that address individual problems as they arise may be successful in the short term, but they may also set into motion feedbacks and interactions among the different parts of a system that can come into play later. Piecemeal interventions do not prepare a system for dealing with ongoing change and future disruptions.

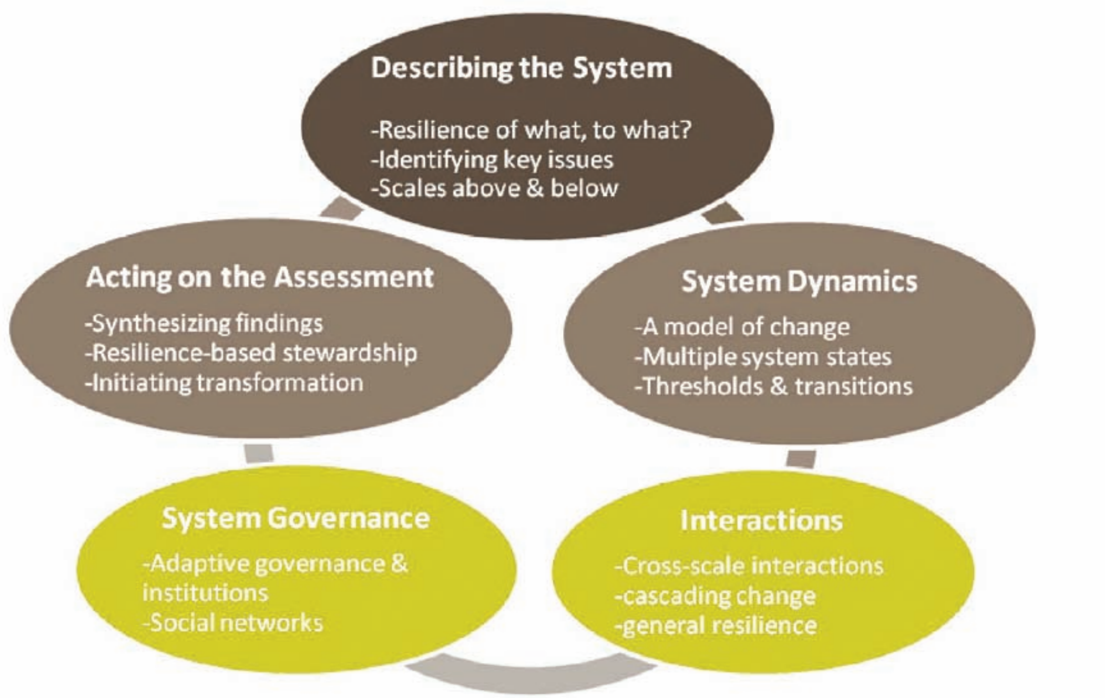
In contrast, an approach to managing natural resource systems that takes into account social and ecological influences at multiple scales, incorporates continuous change, and acknowledges a level of uncertainty has the potential to increase a system's resilience to disturbance and its capacity to adapt to change.

The resilience assessment framework presented in this workbook starts by using strategic questions and activities to construct a conceptual model of a social-ecological system that represents a place of interest, along with its associated resources, stakeholders, institutions, and issues. Building on the conceptual model, the assessment guides the identification of potential ***thresholds*** that represent a breakpoint between two alternative system states and helps reveal what is contributing to or eroding system resilience. A resilience assessment can thus provide insight into developing strategies for buffering or coping with both known and unexpected change.

Resilience assessment draws on research insights from complex adaptive systems and integrates a set of key concepts to provide an alternative way of thinking about and practicing natural resource management. Decades of theoretical research and case-study comparisons by members of the Resilience Alliance and other researchers have contributed to a better understanding of the dynamics of change in social-ecological systems. In contrast to attempting to control natural resources for stable or maximum production and short-term economic gain, a resilience approach assumes an uncertain and complex natural-resource context and aims to achieve sustainable long-term delivery of environmental benefits linked to human well-being. This workbook is designed to assist in resolving specific resource issues and in developing and implementing management goals without compromising the resilience and integrity of the system as a whole.

Figure 1. Resilience assessment framework.

There are five main stages of the assessment framework, beginning with describing the system, then understanding system dynamics, probing system interactions, and evaluating governance, and finally acting on the assessment. The actual process is iterative and reflexive at each stage and requires referring back to earlier steps and revising as necessary.



Resilience is fundamentally a system property. It refers to the magnitude of change or disturbance that a system can experience without shifting into an alternate state that has different structural and functional properties and supplies different bundles of the ***ecosystem services*** that benefit people. Classic examples of shifts between alternate states include transitions from coral reefs to algae-covered rocks, from grasslands to shrub-dominated landscapes, and from clear to cloudy water in freshwater lakes. Associated with each of these shifts are changes in the supply of ecosystem services, for example fish production, grazing potential, and tourism and recreation opportunities.

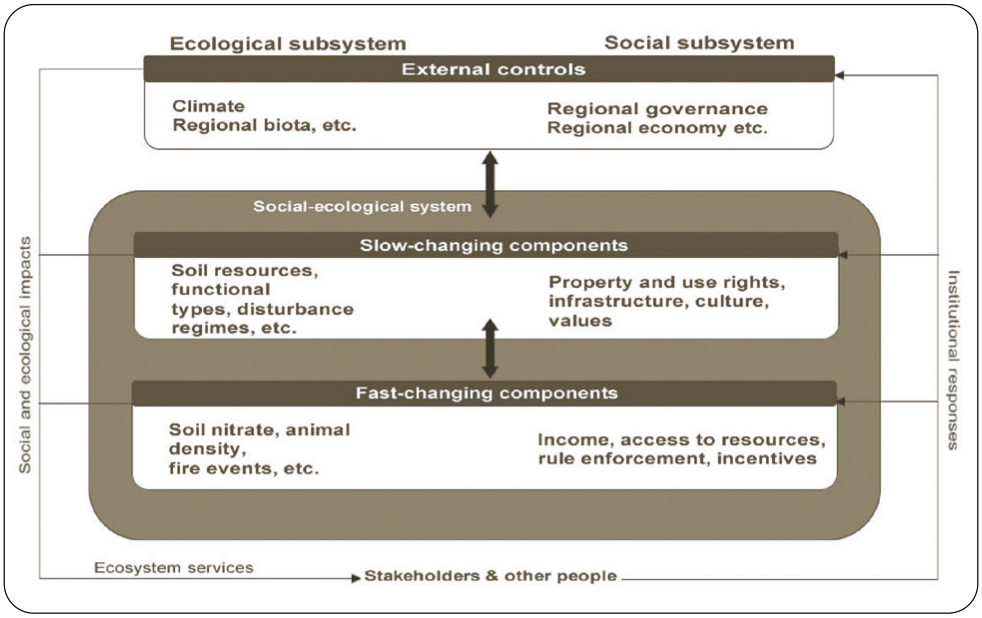
The following paragraphs provide a brief introduction to the key concepts that comprise the resilience assessment framework. These concepts are further described in the rest of the workbook. Presented together here, they provide an overview of the resilience assessment framework and a glimpse into how understanding the change dynamics of integrated social-ecological systems can offer insights into management options under conditions of uncertainty and change.

Integrated social-ecological systems

Central to resilience thinking is the concept of a ***social-ecological system*** (SES). Natural resource management issues are not just ecological or social issues, but have multiple integrated elements. These systems, in which cultural, political, social, economic, ecological, technological, and other components interact, are referred to as social-ecological systems (Figure 2). Social–ecological systems emphasize the “humans-in-nature” perspective in which ecosystems are integrated with human society.

Figure 2. Conceptual model of an integrated social-ecological system.

Ecological components interact with social components at multiple levels. Processes external to the system influence slow-changing components, which in turn influence faster-changing components that impact people more directly. People respond to system changes through institutional mechanisms, creating feedback loops that affect environmental benefits and human well-being (modified from Chapin et al. 2006, PNAS).



The framework for a resilience assessment is constructed around the concept of a social-ecological system. Like other types of systems, a social-ecological system is made up of many different parts that interact to form a more complex entity. The systems approach is holistic because it does not focus on a detailed understanding of parts, but on how key components contribute to the dynamics of the whole system. Parts of an SES respond to changes in other components, sometimes triggering ***feedbacks*** that can amplify change in the whole system or can have a stabilizing effect. Through these interactions, social-ecological systems can self-organize (i.e., adjust themselves through interactions among their components), novel configurations can emerge, and adaptation is made possible. This feature of integrated social-ecological systems can make managing them a challenge, but it also creates opportunities for recovering or reorganizing following a disturbance.

The resilience assessment framework involves constructing a model of the system of interest (i.e., the place, issues, and people involved). Although some activities and questions address individual system components, these insights are meant to contribute to our understanding of the dynamics of the whole system. Each of the assessment questions and activities corresponds with a different part of Figure 2. A final synthesis of the assessment findings, along with the conceptual model, helps to reveal factors that may be eroding or enhancing resilience in the system. This understanding forms the basis for considering options to ensure a sustainable future trajectory.

Multiple system states and critical thresholds

Systems can change over time and may eventually shift into a different ***system state***. The term "system state" refers to a set of social and ecological variables that can fluctuate and create either stabilizing feedbacks that keep a system in a particular state (e.g., a clear lake) or amplifying feedbacks that push the system toward a new configuration and system state (e.g., a murky lake). Specific feedbacks are unique to different types of systems. For example, phosphorus accumulated in mud at the bottom of a lake can provide an amplifying feedback by supporting algal growth and murky water. In another example, sunlight reflected by white snow minimizes warming and melting, thus generating a stabilizing feedback on the snowpack, while darker bare patches of ground or dirty snow will more readily absorb the heat of sunlight, leading to further melting, thus generating an amplifying feedback effect on the snowpack.

Often the transition between states can be slow and gradual, but at other times it can be abrupt. Being aware of critical thresholds between system states can potentially provide advance warning of impending change as well as opportunities for preventing undesirable shifts in system states. In most cases, people become aware of thresholds only once they have been crossed and environmental benefits disappear, with no obvious way of returning to the way things were. An abundance of examples include well-known system shifts like the desertification of the Aral Sea and the collapse of the cod fishery off the coast of Newfoundland, Canada.

Resilience can be represented by the distance between a system state and a critical threshold. This distance, and therefore the resilience of the system, varies over time in response to variation in social and ecological factors. Even if the exact location of a threshold is unknown, simply being aware of a threshold can help reduce the likelihood of crossing into a new state.

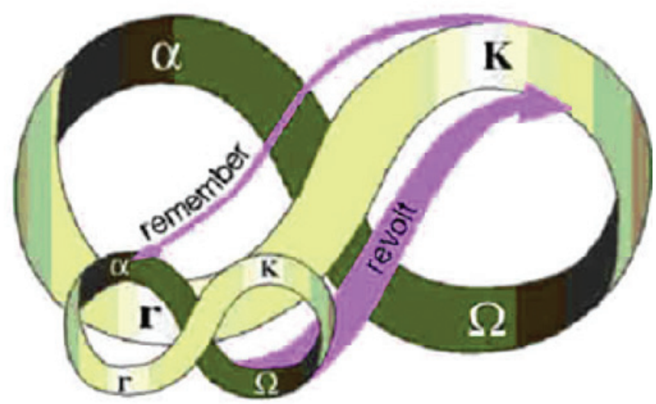
Adaptive cycle and Panarchy

The dynamics of social-ecological systems can be explored using the various phases of change that most natural systems go through over time. Ecosystems tend to cycle through four phases, which can be described as rapid growth (r), conservation of resources (k), release of resources (Ω), and reorganization (α). These four phases, collectively called the ***adaptive cycle***, describe how systems change over time. Forest fire regimes can be used to illustrate these phases, beginning with rapid growth of colonizing plant species (r), conservation of nutrient resources and maintenance of structure in mature forests (k), release of nutrient resources through fire (Ω), and forest renewal through the soil seed bank (α). Social-ecological systems also exhibit different phases of change. Understanding how a system changes internally, in terms of its ***vulnerability*** to disturbance and its capacity to respond as it moves through different phases of change, can inform the type or timing of management interventions. Actions taken during one phase may affect the system quite differently than the same actions taken at other times, and windows of opportunity may be brief.

Figure 3 illustrates the four phases of the adaptive cycle with the added dimension of systems connected hierarchically across ***scales.*** This configuration of linked adaptive cycles at multiple scales is referred to as a ***Panarchy.*** What happens in a system at one scale can affect what happens at other scales. Managing a social-ecological system therefore requires an understanding of what is happening at multiple scales and how the focal system responds to constraints imposed from larger-scale systems or to innovation from smaller nested scales.

Figure 3.

The panarchy diagram illustrates cross-scale linkages among systems represented by the adaptive cycle (modified from Gunderson & Holling, 2002).



Adaptive Governance

Adaptive governance approaches recognize cross-scale interactions and promote interactions across organizational levels. Society is made up of a myriad of rules, some formal, others informal such as cultural practices that determine how people interact with the ecosystems around them. Formal institutions consist of codified rules such as constitutions, laws, organized markets, and property rights, while informal ***institutions*** include the rules that express the social or behavioural norms of a family, community, or society. Together, these interacting institutions form the ***governance system*** that guides how society functions and makes decisions. Adaptive governance is a particular form of governance that emphasizes the capacity to adapt to changing relationships between society and ecosystems in ways that sustain ecosystem services. Characteristics of adaptive governance include experimentation; new policies for ecosystem management; novel approaches to cooperation and relationships within and among agencies and stakeholders; new ways to promote flexibility; and new institutional and organizational arrangements. Adaptive governance systems can enhance general resilience by encouraging flexibility, inclusiveness, diversity, and innovation.

How to approach the assessment

The concepts and activities in this workbook have been developed to help refine a mental model of a system that encourages change, variability, and diversity rather than one based upon controlling system components.

Using an issue-based approach, specific concerns about a natural resource system help to focus and direct the resilience assessment. Each section of the workbook describes a key concept and asks a series of questions or proposes activities that apply the resilience concept to the focal system. Each assessment is unique, not all questions and activities will be equally applicable to all cases. Some sections may be worth spending more time on than others depending on the focal system and key issues that help frame the assessment. Each phase of the assessment builds upon and integrates understanding from previous sections. Brief summaries at the end of each section capture critical insights and are used to construct a conceptual model of the system.

A resilience assessment is time-sensitive and should be revisited regularly as system dynamics change and as understanding grows. The workbook activities are intended to further a process that involves questioning assumptions and being open and flexible to changing how things are perceived. It may be necessary, either during the process or in future iterations, to adjust initial boundaries and to fine-tune sections of the assessment as new information becomes available or as new understanding emerges. Throughout the assessment, it is essential to confront complexity by identifying the key variables and simplifying the system model to bring clarity to the assessment and the actions that will follow.

1 SETTING SOFT BOUNDARIES – DEFINING THE FOCAL SYSTEM

The first step in a resilience assessment is to define the social-ecological boundaries of the system that will be assessed. These boundaries, both spatial (e.g., a catchment or region) and temporal (e.g., over a five- or fifty-year period) comprise what is referred to as the focal system. Identifying the main issues of concern for an assessment is the first step toward defining these boundaries.

There is no perfect way to set the boundaries of a system. Initial assessments may need to be changed as understanding of the system deepens. Any system is influenced by factors that lie both outside and within its boundaries. A full resilience assessment must therefore consider cross-scale system interactions. In this section, we consider primarily the focal system and its subcomponents; in later sections, nested systems at scales above and below the focal system will be considered.

The assessment process assists in determining the critical system components to be included in a conceptual model of the focal system, which will form the basis of the assessment. However, our understanding of what is and is not critical is likely to change as our understanding of the system and issue(s) improves. Reflexivity and a willingness to adjust focal system boundaries and critical system components are fundamental parts of doing a resilience assessment.

1.1 IDENTIFYING THE MAIN ISSUES

A resilience assessment is framed around one or a few related issues to provide a degree of focus. In many cases, the issue(s) to be considered are readily apparent, such as soil salinization, over-harvesting of resources, or threatened ecosystem services. The issue itself may be highlighted by the motivation to do a resilience assessment. In other cases, the main issue(s) may differ depending on the perspective of each stakeholder. Identifying and defining the main issue(s) normally require a diversity of perspectives from various individuals, from those formally trained in particular disciplines to those with an informal but insightful understanding of the system. Identification and characterization of the main issues is an iterative process. Discussions later in the assessment will consider related issues, cross-scale interactions (see Section 3.1), and general system resilience (see Section 3.3).

EXAMPLE: Defining boundaries for resilience assessment in the Grand Canyon.

Over the past century, dams have been constructed along the Colorado River to stabilize water flow, generate electricity, and provide water to the arid regions of the southwestern United States. Flood protection and provision of water for human use (consumption and irrigation) are the primary purposes of controlling water flow in the Colorado River.

The Grand Canyon occupies a reach of the river bounded upstream by the Glen Canyon Dam and downstream by the Hoover Dam. These dams provide a way of bounding the river system for analysis in terms of administration and control points for key ecological processes. However, it is not easy to use these structures as bounds because some ecological processes extend far beyond the dams, while others do not. A more useful place to start is therefore to define the issues that the assessment will seek to address.

Before the Colorado River was dammed, it experienced extreme flow variations, large sediment loads, and seasonally large fluctuations in temperature. Today, downstream of the Glen Canyon Dam, the altered river system has relatively stable flow, clearer water, and a near-constant temperature year-round. The water flows of the Colorado used to vary on time scales of months to decades, with a strong annual cycle. Currently, the largest flow variation occurs on a daily basis and is associated with water releases to generate electricity. These changes have had unforeseen consequences, such as the extinction of seven species of native fish, the endangerment of four others, and a loss of habitat types.

Present management issues involve the declining populations of the humpback chub and kanab amber snail. Water temperature, flow, tributary inputs, and predation by non-native fish have all contributed to their continuing endangerment. Because these two species have received special protection under the U.S. Endangered Species Act, their recovery is a primary management goal, and any management action must not harm these populations. Another key management challenge is how to restore sediment inputs and to retain current sediments within the system. Keeping sand on the banks is important to the large recreational community who camp on the beaches and to the conservation of cultural artifacts along the river.

Mitigation and amelioration of dam effects are therefore primary management objectives. As such, the time frame for assessment and issue resolution is on the order of decades.

Assessment

1. Consider the main issues that need to be addressed in your focal system. There may be one central issue, or there may be a set of related issues. Take, for example, the case of the Grand Canyon. Here, one issue is the recovery of endangered species (humpback chub and kanab amber snail), and another related issue is restoring and retaining sediments within the system.

2. In considering the main issue(s), identify system attributes that are valued by stakeholders. For example, native biodiversity is a valued attribute of the Grand Canyon system.

Enter the main issue(s) and related valued attributes in the worksheet found on the next page. Add additional rows if necessary.

Worksheet 1.1 Summary of main issues of concern for the assessment and of valued attributes of the system.

Issues	Main issue(s) of concern for the assessment	Valued attributes of the system
Issue 1		
Issue 2		
Issue 3		

Discuss

3. Consider to whom the valued attributes are important. Would all stakeholders consider biodiversity, for example, to be a particularly important attribute of the issue(s) you have identified?

4. Given the main issue(s), what is an appropriate time span over which to examine this system? For example, the time span may reflect a planning cycle or be determined by a natural cycle. Consider this to be a first approximation to a relevant time scale, which will be revisited after completing a historical timeline in Section 1.4.

5. Is the main issue already being actively managed? If so, how effective has this management been? Note that institutional and governance challenges will be explored in more depth in Section 4.1.

Reflect & connect

As you progress through subsequent steps in the assessment, be prepared to return to this section to revisit and possibly revise both the main issue(s) as identified and their valued attributes.

Summarize

Succinctly state the main issue(s) to be addressed in the assessment and the time frame of relevance to the issue.

1.2 RESILIENCE OF WHAT? KEY COMPONENTS OF THE SOCIAL-ECOLOGICAL SYSTEM

Once the main issue has been determined, it is necessary to identify the key components of the social-ecological system that are relevant to the main issue. If, for example, changes to a forest's fire regime are a key issue framing the assessment, then the assessment must address the resilience of the forest system to fire disturbance under increasingly unpredictable circumstances. Key components of the social-ecological system might include both the biophysical properties of the forest (e.g., tree species, stand age, climate variables, and changes in fire regime) and the social properties (e.g., residential development, forest monitoring programs, and economic incentives to control fire).

In addition to assessing the resilience of an SES to something specified and defined, it is also necessary to consider general system-wide resilience (Section 3.3) to determine whether actions taken to address a main issue could unintentionally degrade general system resilience.

Identifying the key components of the SES, including social (economic, political, and cultural) and ecological factors, will once again require a diversity of perspectives. Insights from both scientists and local or informal knowledge holders can provide useful understanding of the key components of your defined focal system.

Assessment

1. What are the main uses of natural resources in the focal system? Consider economic, subsistence, recreational, cultural, and conservation uses. Consider also the perspectives of others not present. Are there additional uses that they might add to the list?

Enter this information in worksheet 1.2 on the following page.

2. Are there additional important indirect benefits that are derived from the focal system? For example, ecosystem services such as the provision of clean water, carbon storage by forests, wildlife habitat, and erosion regulation all provide benefits to people. (See Appendix 1 for different types of ecosystem services that you may wish to consider.)

Enter this information in worksheet 1.2 on the following page.

3. Consider the key ***stakeholders*** in the focal system. The term "stakeholders" refers to individuals and organizations that have a stake in the management of the resource in question. They might include those who make decisions about or derive benefits from the resource and those who may be affected by changes in resource supply or management. Consider also stakeholders that are not located within the focal system (e.g., many water users live downstream from key catchments, and hydroelectric power is frequently sold internationally).

Enter this information in worksheet 1.2 on the following page.

4. Draw lines on worksheet 1.2 to connect resource uses with stakeholders. If there are resource uses remaining that are not linked to a stakeholder, consider who is missing from your list and whether they should be added.

Worksheet 1.2 Direct and indirect uses of key natural resources supplied by the system and the stakeholder that rely on them.

Natural resource uses	***Stakeholders***
Direct uses	Inside focal system
Indirect uses	Outside focal system

Discuss

5. Referring to your list of resource uses and stakeholders, what is the level of resource dependence in the focal system? Differences in the level of dependence on natural resources may mean that the needs of various stakeholder groups may have to be considered differently.

6. Consider the property rights in your focal system. Are the resources held under public, private, or common property, or a combination thereof? Are there additional rights (e.g., access) or conflicts associated with the resource? Discuss how existing property rights might influence the kinds of management interventions that are possible in your focal system.

Reflect & connect

Have your discussions about resource dependence and property rights altered your lists of resource uses and stakeholders or the main issue(s) of concern? If necessary, revisit the worksheets and revise as needed.

Summarize

Create a summary list of the key resource uses, ecosystem services, and stakeholders in the system.

1.3 RESILIENCE TO WHAT? DISTURBANCES, DISRUPTIONS, & UNCERTAINTY

Disturbances, disruptions to the system, and uncertainty around the timing and magnitude of such events all present challenges to the management of social-ecological systems and the reliable supply of ecosystem services, including the provision of resources.

A disturbance can generally be thought of as anything that causes a disruption to a system. Disturbances in social-ecological systems can include drought, fire, disease, or hurricanes, as well as recessions, innovations, technological change, and revolutions. Human intervention in an ecological system can also be a form of disturbance, for example the building of irrigation canals, intensive fishing, or mining operations. As populations and consumption levels grow, human-caused disturbances can intensify, with consequences for a system's general resilience.

A disturbance that occurs as a relatively discrete event in time is referred to here as a "pulse" disturbance, while more gradual or cumulative pressure on a system is referred to as a "press" disturbance. Both types of disturbances can be part of the natural variability of a social-ecological system. Understanding a disturbance regime, i.e., the pattern of disturbance events over time, can inform how to work with the disturbance regime as opposed to attempting to control or prevent it, which may ultimately weaken a system's resilience.

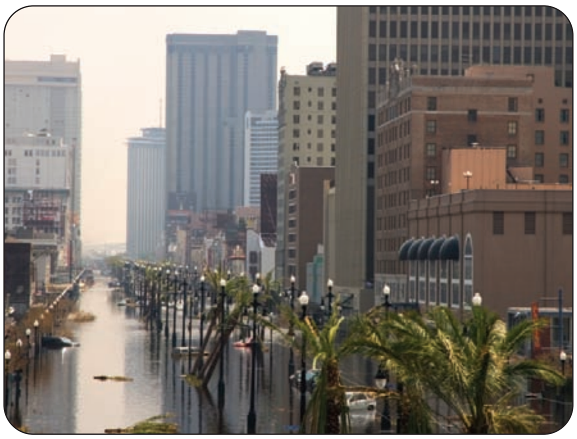
Disturbance regimes can also change over time and have an inherent degree of uncertainty. Exactly when a lightning bolt might ignite a forest fire is impossible to predict, but estimates of fuel load, degree of connectedness to surrounding forests, stand maturity, and weather conditions can help reduce the level of uncertainty around the timing and size of a future fire. Whether your goals involve sustainable harvests, securing infrastructure, or protecting habitat, accommodating and mitigating disturbances can, over the long term, minimize the impact of individual events.

There are many ways to characterize disturbances, for example their frequency, duration, severity, and predictability. This information can contribute to understanding a system's disturbance regime. In addition, any given system may be vulnerable to a suite of different disturbances. Combinations of disturbances and the timing of events can cause interaction effects. An otherwise benign disturbance may have much greater consequences if it follows another disturbance from which the system has not yet had a chance to recover.

Similarly, systems that have been "protected" from particular types of disturbances may not have the capacity to cope in the absence of such protection. Management strategies that strive to control disturbances excessively, for example by reducing variability to improve efficiency, can erode system resilience, making the system increasingly susceptible to even small disturbance events that it would otherwise have been able to accommodate.

EXAMPLE: Testing Urban Resilience - When disturbance becomes disaster: Hurricane Katrina and New Orleans.

The city of New Orleans, situated along the Mississippi River in the southeastern United States, has developed around the river and for over two centuries has been a major commercial seaport. From early on, the city sought to control the river. Because of flood control and water management in the Mississippi River basin, the sediment that once replenished the soils of the delta has moved out into the Gulf of Mexico. Because of the lack of sediment input combined with soil subsidence, many parts of the city are now below sea level.



Flooding in New Orleans can occur from high rainfall over the drainage basin or from storm surges associated with tropical cyclones. Because of its precariously low elevation, New Orleans is protected from flooding by a system of levees and canals. This system of defences was built in a piecemeal fashion over time as successive governments invested in infrastructure in an attempt to control floods. New structures accumulated in response to predictable flood events that revealed the inadequacy of the levees to control natural variability.

In 2005, the flood-control system was overwhelmed by Hurricane Katrina. The accompanying storm surge raised water levels in the surrounding open waters. A number of levees failed because the hydraulic pressure from the high water caused part of the levee substrate to slip, resulting in levee failure. Nearly 80% of the city was inundated, with some areas lying four metres under water for weeks following the storm. Losses were estimated at more than $20 billion U.S. More than 1,200 lives were lost. The federal government, which normally takes a lead role in disaster relief, was seen as slow to react and incompetent. The myth of flood protection by the federal emergency response agency was shattered. Widespread looting, crime, and loss of basic life necessities heavily impacted the most vulnerable populations because law enforcement was nonexistent and informal networks were unable to maintain order.

Hurricanes and floods are both disturbances that originate from processes occurring at larger scales. At city scale, storms can cause massive disruption, the degree of which is partly related to how resilient a city is to such events. Hurricanes such as Katrina have hit coastal Louisiana before and will do so in the future.

Assessment

1. What disturbances have historically affected your focal system? What disturbances presently represent a concern, including potential future disturbances? Consider both “pulse” disturbances that occur as singular events (e.g., plowing, hurricanes, disease outbreaks) and “press” disturbances that occur continually (e.g., a grazing land stocked year-round or continued shoreline erosion).

Enter this information in worksheet 1.3 on the following page.

2. Looking at worksheet 1.3, which of the disturbances listed are actively managed or suppressed? Is there any reason to believe that efforts to suppress disturbances are potentially making the system more vulnerable? Should any specific management strategies relating to disturbance abatement be reconsidered?

Worksheet 1.3 Summary of focal system disturbances and their attributes.

Disturbance (past or present)	Pulse or Press	Frequency of occurrence	Time for recovery between occurrences	Components most affected (e.g., soil, markets)	Magnitude of impact (minor to severe)	Any change in past years or decades? (none, less frequent, more intense, etc.)
Future disturbances						

Discuss

Have any of the disturbances that you have identified in the past fundamentally altered the nature of your system or caused it to change in a fundamental way?

Which disturbances pose the greatest threat to the valued attributes of your focal system?
If you indicated any changes in disturbances over time (e.g., changes in magnitude or frequency), do you know what might be driving these changes?

Did you identify any "press" disturbances in your system? If not, give some thought as to whether or not "press" disturbances might have been overlooked in your system model (e.g., press disturbances might be tied to economic incentives or a change in values).

Reflect & connect

Have your discussions about disturbances in your focal system altered in any way the main issues of concern that you identified in Section 1.1? If necessary, revisit the issues as you originally described them and revise them as needed.

Summarize

- Summarize the critical disturbances affecting (or having the potential to affect) your focal system in terms of their frequency and impact.
- Indicate any significant changes in disturbance attributes (e.g., magnitude, frequency).
- Indicate whether any current management strategies that attempt to control or suppress natural disturbance regimes are potentially problematic.

1.4 EXPANDING THE SYSTEM - MULTIPLE SPACE AND TIME SCALES

The focal system at the centre of a resilience assessment is connected in various ways to a hierarchy of nested systems that function at multiple space and time scales. What is happening at larger spatial scales can influence the focal system. For example, climate change, government regimes, and cycles of pest outbreaks at continental scales can strongly interact with focal system dynamics. Similarly, smaller systems nested within the focal system can generate change from within. For example, when small patches of coral reef become degraded, they can jeopardize the resilience of a much larger area by interrupting the supply of coral larvae to surrounding reef patches, which can potentially lead to a cascading collapse of the larger reef system.

Social-ecological systems also undergo change over time. Those changes can be slow and predictable or fast and unexpected. A broad overview of system change through time can reveal patterns of past disturbances and responses as well as the impacts of cumulative or gradually changing variables like the number of households in a village or harvest rates of particular species. Understanding what is behind these changes—the change drivers—can provide insight into how historical system dynamics have shaped the current focal system and what effects they might have in the future. A historical profile of the system can also reveal changes in system resilience over time, including those that occur in response to specific human interventions, whether intended or not.

In most ecological systems, there is a general relationship between spatial and temporal scales: larger systems tend to change more slowly and less frequently (e.g., the chemistry of the ocean in which the coral reef exists), and smaller systems such as individual corals or small patches tend to change more rapidly and frequently relative to the whole reef system. This time-space relationship does not always hold, however, for instance when large-scale social change or hurricanes occur rapidly or an individual's principles and values change gradually. As a general guide, though, one can look first to larger-scale dynamics when trying to identify the slowly changing variables that help stabilize a system within a particular regime.

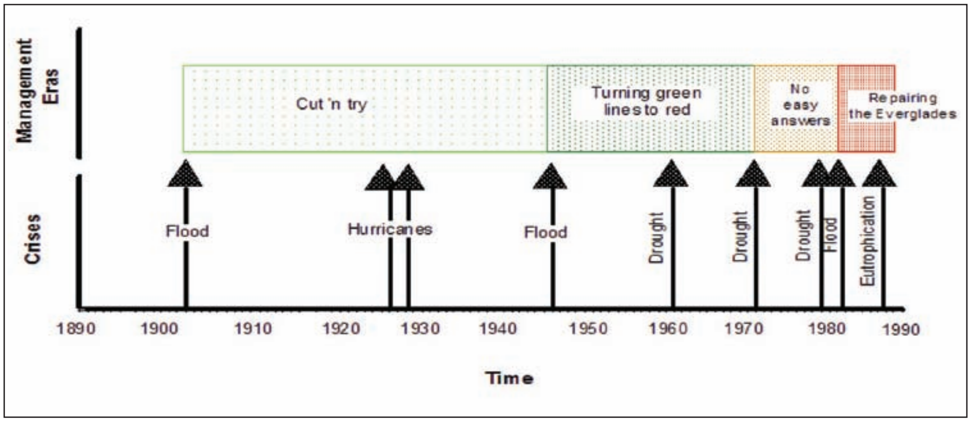
When crises occur at smaller or larger system scales, they can signal or accompany a loss of resilience at the focal scale. They can also serve as windows of opportunity for change. Cross-scale interactions can influence the focal system dramatically. These types of cross-scale interactions will be explored further in Chapter 3 of the assessment. Here we are interested primarily in identifying systems operating at scales above and below the focal system as well as developing a historical timeline of change in the focal system.

Example: Historical timeline of Everglades management eras

The history of water management in the Florida Everglades during the 20th century demonstrates regime shifts and related changes in resilience over time. During this period, at least four management regimes can be identified and attributed to specific events (e.g., flood, storm, drought, or change in management). Figure 4 illustrates the four management regimes along a timeline from 1900 to 1990.

Figure 4.

Timeline of historical management regimes and key disturbance events in the Florida Everglades between 1900 and 1990 (Gunderson et al., 1995).



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

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

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

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

Assessment

1. Briefly describe the systems at scales above and below your focal system in terms of their social and ecological dimensions that interact with the focal system in the context of the main issue(s). **Enter a brief summary in worksheet 1.4.**

Worksheet 1.4 Social and ecological dimensions of systems at larger and smaller scales that interact with the focal system.

	Social dimensions that influence the focal system	***Ecological dimensions that influence the focal system***
Larger-scale systems		
Focal System		
Smaller-scale systems		

2. What critical data or information are you missing for the other scales that you have described? ***List any action items for filling in these information gaps.***

3. Sketch a historical profile of the focal system. Include three spatial scales in the historical profile by creating a table with three rows, with the middle row representing the focal system, the row above representing larger-scale system dynamics, and the row below representing smaller-scale system dynamics. The horizontal axis of the diagram is the most relevant timeframe for your focal system (e.g., 100 years ago to the present). Include significant historical events in the profile. Try to identify different eras that are framed by historical transition points and briefly characterize and name each era. Indicate by a dashed line any connections between related events across scales. For instance, was a shift in agricultural production at the focal scale caused by an earlier economic shock at a larger scale?

Discuss

4. With each change from one era to another, what were the driving forces that contributed to or triggered major change?

5. Are there any obvious patterns in the historical timeline? How often do events that trigger change come from the larger scale and how often from the smaller scale? What are the social and ecological dimensions of these trigger events, and are there any patterns of cross-scale interactions that are relevant to the focal system and the main issues of concern today?

Reflect & connect

Are the disturbance regimes and system disruptions that you identified in the previous section included in the historical timeline? If not, should they be?

Has the historical timeline provided any insight into the disturbance regimes of your focal system?

Has the exploration of spatial and temporal scales revealed any new dimensions that can inform the main issue(s) that you identified in Section 1.1?

Revisit the earlier description of your focal system boundaries and reflect on whether you are still comfortable with them. The focal system boundaries do not have to contain the scale of disturbances that may affect your system.

Summarize

- Summarize the trigger event(s) or any vulnerabilities that led to a change from one era to another (in the historical profile).
- Summarize the most critical interactions between the focal system and systems operating at smaller or larger scales.

2 SYSTEM DYNAMICS

2.1 A CONCEPTUAL MODEL OF CHANGE – THE ADAPTIVE CYCLE

Change is always occurring, and if we ignore it or attempt to prevent it rigidly, we may miss opportunities or create new challenges to achieving long-term sustainability. Social-ecological systems can experience both gradual and rapid changes. Managing for resilience requires understanding cycles of change and the vulnerabilities and windows of opportunity that these cycles of change introduce to your system.

The adaptive cycle model can facilitate understanding of how a system changes over time, whether any cyclical patterns of change exist, and how a system's position in the cycle can inform the timing of management interventions. Most systems are dynamic and change over time, often following a pattern of four phases: growth, maintenance, collapse, and reorganization. In general terms, the adaptive cycle describes how a system is established, develops and stabilizes, undergoes rapid change, and then reorganizes itself to begin the sequence again. Often, following reorganization, the new cycle is similar to previous cycles, but occasionally a different trajectory emerges. Transitions between the four phases of the adaptive cycle do not always follow the same sequential pattern. However, the four phases seem to capture the behaviour, structure, and characteristics of many different types of systems (Figure 5).

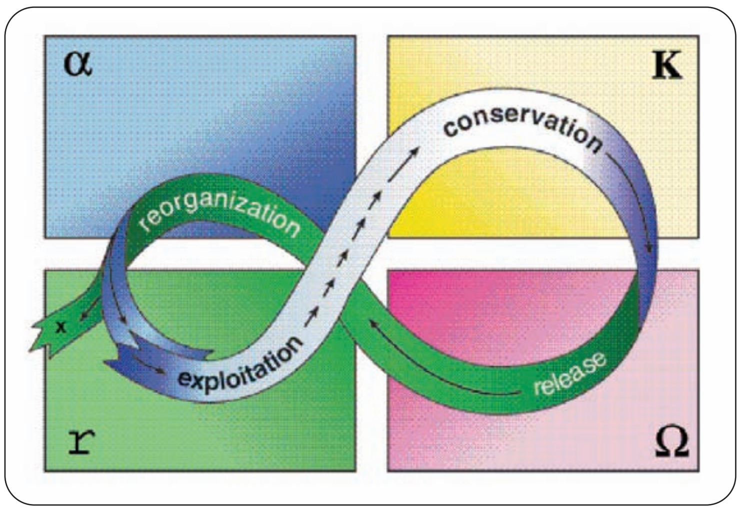


Figure 5. The adaptive cycle. (Gunderson & Holling 2002)

A classic example of the adaptive cycle is the set of cyclic changes that occur in forest ecosystems over time. Following a disturbance, during the organization phase [α], a collection of plants will colonize the site. The composition of this plant community will be shaped both by "old" factors (e.g., seeds left behind in the soil) and "new" factors (e.g., the effect of a forest fire on the soil). Once a group of plants becomes established, rapid development of the forest (growth phase [r]) begins and continues until the forest achieves a more mature structure. In this state, most of the system's resources (nutrients) are held within the forest biomass, and the tree canopy has a strong influence on growing conditions on the forest floor, helping to stabilize the system. This conservation phase [k] may persist for some time until it becomes vulnerable to normal disturbance patterns (such as a windstorm or surface fire) or an unexpected disturbance occurs that rapidly disassembles the system's structure and functioning [Ω]. Following collapse, the system begins to renew itself as new plants colonize the site, and the adaptive cycle repeats (the reorganization phase [α]). In fire-adapted forests, even though particular phases of the cycle come and go, the forest system may be resilient over time. See the Tongass Forest example below for a description of how this process occurred in a much larger and more complex resource management system.

Together, the growth and conservation phases are referred to as the "fore loop" of the adaptive cycle, while the collapse and reorganization phases are the "back loop". In most cases, the fore loop occurs over a much longer period of time than the back loop. Different types of change characterize the fore and back loops: change occurs relatively gradually and predictably during the fore loop, while it occurs abruptly and often unpredictably during the back loop. In this part of the workbook, you should begin thinking about both types of change in your focal system's past, present, and potential future(s).

Example: The Tongass Adaptive Cycle

Industrial forest management in the Tongass National Forest in Alaska (United States) exhibits a remarkable fit with the adaptive cycle. Initially envisioned to serve both economic development and forest management goals, the industrial forestry system of the Tongass was based on large-scale clear-cutting and local processing of both high-grade saw timber and lower-grade pulp products. During the early 1900s, efforts to establish this system in the remote and rugged landscape of southeastern Alaska were hindered by a number of economic and logistical factors. During this organization phase [α], the foundational elements of the Tongass resource system first emerged. Eventually, demand for lumber supplies during World War II created an opportunity to establish the Tongass forestry system. With legislation providing both political authority and economic subsidies to harvest large tracts of primary old-growth forest, the Tongass system was established on the basis of long-term leases that provided guaranteed low-cost timber and other subsidies in exchange for the construction and operation of timber mills in the region. These new factors enabled the Tongass system to change rapidly and led to a period of vigourous growth that lasted over two decades (1948-1970). During the latter years of this growth phase [r], reforms in environmental policy began to erode the authority of the Tongass resource system to harvest timber, leading to a period when the system sought stability in the face of change – the conservation phase [k]. Changes occurring during this time were mostly external to Alaska, but affected the Tongass in many ways, including globalization of timber markets, stronger environmental protection policies, and institutional reforms at the U.S. Forest Service. In 1990, when the U.S. Congress revised the establishing policies and removed timber subsidies during a market downturn for Alaskan forest products, the long-term leases were terminated, and the Tongass system entered the collapse phase [Ω].

Collapse of the Tongass system led to dramatic declines in employment and major changes in local and regional economic conditions. Other legacies of system collapse have been a degraded forest ecosystem and an atmosphere of mistrust among managers, stakeholders, and policymakers. As of 2010, the Tongass remains trapped in the collapse phase, unable to reorganize and begin a new adaptive cycle. A primary reason for this is that the system rigidly resisted change instead of being adaptive to change. Another lesson from this case study was that change—i.e., a shift from one phase to the next—occurred in the Tongass system only when several subsystems (economic, institutional, political) moved simultaneously to the next phase. In other words, the larger system did not experience dramatic change until several smaller-scale factors pushed it in a single direction.

The Tongass National Forest case study illustrates several concepts that are important to consider when applying the adaptive cycle. First, during the “fore loop” of growth and conservation (r and k phases), Tongass managers emphasized efficiency (in harvesting timber) over flexibility (in providing other forest values), and this encouraged a rapidly growing but increasingly rigid system. Second, the maintenance of ***capital*** during the “back loop” is essential for reorganization and renewal. Although the collapse of the Tongass timber industry had negative consequences for many communities in the region, the overall SES of Southeast Alaska was resilient because much of the region’s natural and social capital remained intact. In particular, the maintenance of strong connections between local residents and natural resources through subsistence and personal-use harvesting of fish and wildlife fostered a relatively smooth transition towards rapid growth in the ecotourism and guide/outfitter industries that followed the collapse of the timber industry. By contrast, the pervasive loss of trust among stakeholders (a form of social capital) has greatly constrained progress in the reorganization of Tongass governance for nearly thirty years.

Assessment

1. Apply the adaptive cycle framework to your system. Referring to the historic timeline that you developed in Section 1.4, try to identify the phases of the adaptive cycle through which your system has moved over time. The precise timing of phase transitions is not as important as describing the key factors that drove the system through the cycle.

2. Select one or more key variables that can serve as indicators of how your focal system has changed over time. For example, in the Tongass adaptive cycle, the annual volume of timber harvested provides a basis for interpreting how a variety of economic, political, and institutional changes have affected the overall system. Tracking key variables over time can provide insight into the timing and nature of the changes in your system. Examples might include the volume of a commercial fishery, employment by sector, institutional budgets, and carbon storage. In the absence of data, you can make relative estimates of changes in variables from phase to phase.

Discuss

3. Which change-causing drivers or factors appear to play a major role in the functioning of your system?

4. What types of natural and social capital should be maintained in your system, regardless of changes that might occur, to enable reorganization and renewal?

5. Considering tradeoffs between efficiency and flexibility, does your focal system depend on producing a specific set of outputs under a specific set of conditions?

Reflect & connect

Considering scales above and below your focal system (Section 1.4), are there other adaptive cycles at play outside your focal system that might influence your system's trajectory (this concept will be discussed further in Section 3.1)?

Has the analysis you just performed changed your understanding of the main issues of concern for your assessment?

If necessary, go back and add to the historical timeline that you created in section 1.4.

Summarize

- List the 3-5 key factors that drive change in your focal system.
- List key variables that could be used to track change in your focal system.
- Identify the phase of the adaptive cycle in which your focal system currently exists and summarize your assessment of change dynamics in your system using the adaptive cycle model.

2.2 MULTIPLE STATES

Understanding the resilience of your system involves describing its current state as well as its historical and potential future states. A state is defined by its key components and how they interact, function, and respond to changes that are both internal and external to the system (Section 1.2). Although individual components have a definable role in the system, the relationships among components are what shape the system as a whole. Interactions among species in an ecosystem through mutualism, competition, or predation, for example, help define a system's structure and function, while social systems rely on interpersonal relationships that shape our norms, values, and institutions. Not only do these relationships enable systems to function, but they also determine how a system can respond to change.

When we think of the countless components of our social-ecological systems and all their potential interactions, the picture that emerges is often overwhelming. The concept of a system state helps us "boil down" this complexity into something more manageable. One guideline for doing this is called the "rule of hand", whereby any system can be described by a small number (usually 3-5) of key variables that characterize and determine its current state. The conditions of these key variables and the nature of their relationships are equally important considerations for defining the state of the system.

Many systems can exist in more than one stable state (Figure 6). These "alternate states" may have occurred in the past or could emerge in the future. The term "stable" here does not mean fixed and unchanging; typically there is some variation within a relatively stable domain. Therefore, we can still speak of system dynamics in reference to a stable state.

The dynamics of a system can be determined using simple measurements, such as the volume of forest products yielded annually in a working forest landscape, or in more complex ways that require looking more closely at how the system changes and why. For example, in a working forest landscape, interactions among factors like forest composition and productivity, local management practices, regional industry structure, and global markets should be investigated.

Some system states are extremely stable; in some cases, these are referred to as "traps" because they are difficult to change and the particular state and the ecosystem services it supplies may not be desirable to stakeholders. A system can have strong forces acting upon it to keep it in a particular state.

Figure 6.

Grass-dominated and shrub-dominated states of a northern Australian savanna illustrate two alternative system states. Interactions between grazing pressure and fire control the savanna state.

Assessment

1. Describe the alternate states of your focal system (you may find it useful to refer to your work in Sections, 1.2, 1.4, and 2.1).

2. Describe the historical state(s) of your system, referring to the timeline that you developed in Section 1.4. Keep in mind that phases of the adaptive cycle can be treated as different system states at specific points in time (e.g., the majority party in a representative democracy or the dominant plant species in a forest ecosystem) or a broader view of the system state can be adopted (e.g., the system remains in the same state as long as it remains a democracy, or as long as it remains a forest and does not become a grassland or desert). Both approaches may be helpful depending on the issue or scale that you are addressing in your system.

3. Describe the transition phases between alternate states in your system. What is the degree of reversibility between alternate stable states based on your understanding of the transitions? You may find it helpful to sketch a diagram that includes the alternate states and the key factors or processes that occur during a transition phase from one state to another.

4. Are there particular desirable or undesirable traits associated with each alternate state, upon which stakeholders might agree?

Discuss

Using the "rule of hand", what 3-5 factors are the most important to consider in defining the state of your system?

How do these factors and their interrelationships change as the system state changes?

Reflect & connect

How do the alternate states of your system map onto the adaptive cycle? In other words, are they represented by different phases of the adaptive cycle, or would they be more accurately described using separate adaptive cycles?

Are there undesirable alternate states that are to be avoided or from which you might want to transition away? What are the main challenges associated with moving away from these undesirable states?

Summarize

- Describe the alternate states of your system, using the Rule of Hand to reduce complexity.
- Describe the changes in key variables that determine a transition between alternate states.

2.3 THRESHOLDS AND TRANSITIONS

Managing for resilience requires understanding how a system moves between multiple states and, where possible, learning how to facilitate transitions to achieve desired outcomes. Every transition involves crossing one or more tipping points, or thresholds, that separate alternative system states. Thresholds explain how a system can experience gradual change and appear relatively stable, and then experience sudden instability and rapid change over a relatively short period of time. Abrupt or unexpected transitions can limit the opportunity for proactive decision-making. In other cases, transitioning into an alternative system state may be a management objective that can be achieved through careful planning, stakeholder involvement, and adaptive decision-making. A key challenge in either case is presented by the thresholds themselves, which tend to be neither static nor simple to identify. Therefore, it is often more important to identify the factors that will push your system beyond a threshold than to estimate the precise conditions under which a threshold will be crossed.

EXAMPLE: Lakes, Agriculture, and Thresholds

Phosphorus (P) is a common element that is necessary for plant growth and is often added to agricultural fields as fertilizer to increase crop yields. Some of the P is carried in runoff to surrounding areas, including wetlands and lakes, and the added P nourishes plant and algal growth in the lake. Over time, with continuous inputs, the P accumulates in mud (sediments) at the bottom of lakes and supports increased growth of phytoplankton that can result in algal blooms.

The amount (concentration) of P in lake sediments is a key factor determining whether the lake tends to be clear with green plants (one state) or murky with algae blooms (alternate state). The dynamics of the P nutrient cycle that result in algae blooms are complex, as are the factors that trigger a transition between clear water and cloudy water (algal) states. Because the rate at which sediment P concentration changes (decades) tends to be slower than the rate of P inputs from farm runoff (months to years) and is slower than the speed at which algal blooms occur (days to weeks), lake sediment P concentration can be considered a “slow variable”. Although by definition these variables tend to change rather slowly, they can also change quite rapidly and dramatically when a threshold is crossed. As with other cases where resilience is diminished, the threshold associated with lakes that suffer from large and persistent algal blooms is linked to system components that change slowly and that therefore may give the appearance of stability.

A century ago, in many regions, human sewage was typically funnelled into lakes, eventually resulting in state changes in the lake system. Even after decades of water treatment to remove phosphorus from sewage, many lakes have not returned to their original clear-water state. In many systems, once a threshold has been crossed, it is difficult (if not impossible) to return to the previous state. Although “natural” recovery is possible if stressors such as farm runoff are removed, it can take multiple human generations before recovery can occur. During this time, society must cope with the undesirable outcomes of state changes that, in the case of freshwater lakes, may include lower provision of ecosystem services related to water quality, fisheries, and recreation.

Actions taken at different points in time can influence both thresholds and transitions. Before the transitional period, management interventions can avoid threshold crossings by mitigating whatever factors are driving the system towards the threshold. During the transition, after the threshold has been crossed but before the system has reorganized into its new state, management can attempt to shape the trajectory of change and thus influence the initial conditions of the new state. Options for intervening before or during a transition phase depend largely on the state of slow variables (for example lake phosphorus), available sources of natural and social capital, and whether the system condition was nurtured or eroded before the threshold was crossed. Once a threshold has been crossed, changes in the system state may be difficult or impossible to reverse. It is not always possible to restore lake clarity, for example, simply by reducing phosphorus levels to what they were before the threshold was crossed. The threshold phosphorus concentration that triggers a change from a clear to a cloudy lake may not be the same as the threshold that will trigger change from a cloudy to a clear lake.

Assessment

Using the results from Section 2.2 (Multiple States) and the questions below, describe the thresholds and system drivers associated with these state changes.

1. How might the focal system in its current state experience transition into each of the alternate states that you identified previously? Will the transition likely be smooth and gradual or abrupt and sudden? Consider both the trajectory of the system (its direction of change over time) and its key components. For example, the transition in a rangeland as it shifts from grass-dominated to shrub-dominated (due to overgrazing) involves crossing a woody biomass threshold beyond which fire intensity changes, triggering a shift to woody vegetation even if all livestock (the driver) are removed. In this case, although crossing the threshold leads to an abrupt change in system trajectory, the change in components (grasses and shrubs) occurs gradually as grasses give way to shrubs. In contrast, when a lake ecosystem crosses a phosphorus content threshold which drives a shift from clear to murky water, the changes in both the system's trajectory and its observable components (turbidity, algae biomass) occur abruptly.

2. Characterize each threshold of potential concern by indicating the main factors driving the change, its degree of reversibility, and the possible consequences of crossing the threshold. The drivers, or factors responsible for crossing a threshold, are often related to slow variables in the system (such as phosphorus accumulation in lake sediment). If possible, try to identify any slowly changing variables that appear to be system drivers.

3. Can you estimate the approximate location of any of these thresholds? In some cases, it may be possible to estimate thresholds using existing data that capture how the system changes over time in response to a specific driver. For other systems, it may be difficult or impossible to estimate a threshold location because there are multiple dynamic thresholds that change both in response to external factors and in relation to other thresholds.

Discuss

4. How do any of the thresholds you identified in social subsystems interact with thresholds in the ecological subsystems (and vice versa)?

5. Are current monitoring activities sensitive to changes in the driving variables that you identified above? What steps could be taken to improve understanding of the thresholds of potential concern in your focal system?

6. Most existing examples of thresholds in social-ecological systems are derived from ecosystems. Can you identify any thresholds related to the social (economic, political, cultural) dimensions of your system?

7. What do you consider to be the most critical thresholds and the most undesirable states of your system?

Reflect & connect

Are any of the system disturbances identified earlier likely to move the system closer to a threshold?

Summarize

- List the thresholds of potential concern described above and indicate potential interactions among them.

3 CROSS-SCALE INTERACTIONS

3.1 THE PANARCHY

Social-ecological system resilience interacts with and is influenced by larger-scale systems in which it is embedded, as well as with the smaller-scale systems of which it is comprised. Panarchy is a term used to describe a model of hierarchically linked systems represented as adaptive cycles that interact across scales. For example, sources of system memory like seed banks, coral polyps, or knowledge and tradition are often retained by larger-scale systems that can help the focal system retain valued components after disturbance events and facilitate recovery. System memory, however, can also constrain the focal system when change is desirable. At such times, innovation may require loosening connections with larger-scale systems and cultivating tolerance for new conditions and alternative ideas. These sources of novelty often exist within smaller nested subsystems. From a management perspective, not interfering with cyclical adaptive change at smaller scales can strengthen the resilience of the focal system in the same way that allowing smaller forest fires to burn naturally helps to maintain a forest mosaic with stands of different ages, thus preventing larger, potentially catastrophic fire events.

At each level, knowing the present phase of the adaptive cycle of these connected systems can reveal potential vulnerabilities or opportunities in the focal system. Tightly linked smaller-scale systems in similar phases of the adaptive cycle may indicate vulnerability at the focal-system level to the rapid spread of disturbance across scales, causing a domino-effect collapse.

EXAMPLE: Interactions across scales: forest fires

Forest fires do not occur every year in the same place. Although fires may burn different areas during the same year, the same patch of ground does not generally burn again. For this reason, ecologists define a fire frequency or a fire return interval. This interval is related to different processes operating at different time scales.

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

Fires occur when the following set of conditions prevail: sufficient fuel loads, fuels that are connected across an area, dry conditions that foster combustion, and an ignition source. This convergence of conditions can be described as a cross-scale interaction, with ignition operating on a short time scale, plant growth occurring over years, and fuel loads and drought cycles over decades. Spatially, ignition and plant growth are local, while fuel loads can spread fires across large areas, and droughts can occur over even larger areas.

Referring to the Panarchy model, the aggregation of smaller-scale entities (plants that burn) generates the conditions for a release (K-phase) disturbance at the scale of a patch or forest. Forest structure and processes at even larger scales than the fire influence post-fire recovery. Many fire-adapted plants have seeds that are stored in cones for years, to be released only after a fire. Those seeds reflect years of plant growth, not to mention thousands of years of evolutionary pressure. At larger spatial scales, seeds from unburned areas colonize burned areas during the reorganization or back-loop phase. Because the seeds were developed before the disturbance, they are considered part of the system's memory. Infusions of capital in the form of seeds and nutrients in a forest are crucial for post-fire recovery. In the social domain, property insurance (a form of memory), low-interest loans, and recovery funds can also be critical to recovery from natural disasters.

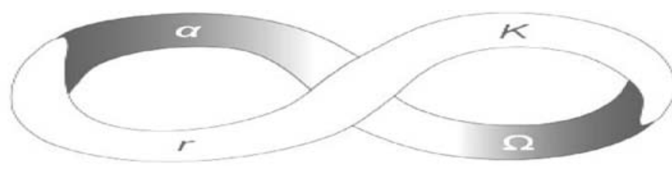
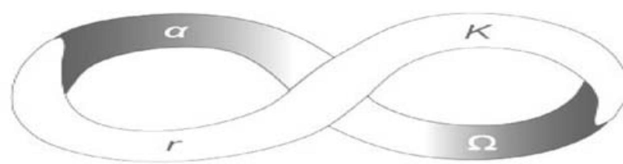
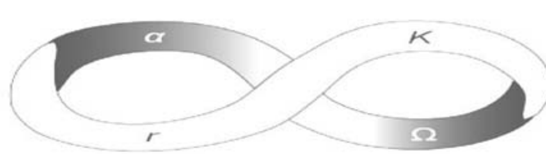
Assessment

1. Refer to the larger-scale system that you identified in Section 1.4. What phase of the adaptive cycle does the larger-scale system appear to be in? On the worksheet below, indicate the approximate location or current phase of the larger-scale system.

2. On the same worksheet, describe briefly the main influences from the larger-scale system(s) on your focal system. Indicate also important sources of memory and capital, including social and ecological sources.

3. Refer now to the smaller subsystems you identified in Section 1.4. On the same worksheet that displays the focal and larger-scale systems, indicate the adaptive cycle phase(s) of the smaller-scale subsystems. Note that a focal system is made up of several subsystems at finer scales. For example, if the focal scale is a watershed, a finer-scale subsystem could be one of the subcatchments that make up the watershed. Similarly, the focal system may be a city where neighbourhoods represent smaller-scale subsystems.

Worksheet 3.1 Cross-scale interactions.

Larger-scale systems	
Focal system	
Smaller-scale systems	

Discuss

4. Considering the phases of the adaptive cycle in which you find your focal system and the larger-scale systems, in what ways do the larger-scale systems either foster change or constrain the focal system?

5. Are the innovations and learning coming from smaller-scale subsystems being captured at the focal scale? If so, how? If not, what mechanisms can be put into place to take advantage of this innovation and learning at the focal scale?

6. Are there any opportunities for leveraging cross-scale interactions to achieve desirable outcomes at the focal scale?

7. Are both the focal system and smaller systems in a conservation phase? If so, how might this situation increase the possibility of disturbance cascading across scales? If large-scale change is to be avoided, what management strategies might help break this alignment?

Reflect & Connect

Review the larger- and smaller-scale systems that you identified in Section 1.4. Revise if necessary.

Summarize

- Summarize both desirable and undesirable influences from larger-scale systems.
- Summarize any system vulnerabilities at the focal scale that you have identified by considering cross-scale interactions.
- Briefly characterize the balance (or tradeoffs) between flexibility and efficiency in your focal system.

3.2 INTERACTING THRESHOLDS AND CASCADING CHANGE

As a system's resilience declines, the size of disturbance that can trigger a shift to a different system state becomes progressively smaller. Usually multiple variables are at play, and the challenge is to identify the critical, slow-changing variables that can either trigger abrupt change or interact with other system variables causing other thresholds to be crossed.

The potential for cascading thresholds underscores the value of an *a priori* understanding of how system variables might be expected to interact. Knowing how likely a particular variable is, if it crosses a threshold, to cause another variable to cross a threshold, or whether it might reduce that potential, have a lagged effect, or have no effect at all, can contribute to understanding system dynamics as they relate to specific critical thresholds that may or may not be receptive to management actions. Although some thresholds may be fixed, others may fall within a range that is partly determined by other variables. Determining the certainty of specific thresholds can also provide valuable information to managers.

Example: Potential Cascading Thresholds in Goulburn-Broken Catchment, Australia

The gradual loss of resilience in the Goulburn-Broken Catchment in southern Australia has left the region vulnerable to climate variability that in past decades would have had no significant effect. A combination of factors has led to a situation in which the possibility of multiple consecutive wet years threatens some of the country's best agricultural land with irreversible soil salinization if the water table rises closer to the surface beyond a threshold level. The largely historical clearing of native vegetation, particularly in the catchment foothills, combined with the extensive development of irrigation infrastructure and reliance on high-tech pump systems to control water table levels, has over time reduced the number of options available to reverse this trend. The region is a major source of food exports for the state of Victoria. Social and cultural values have also driven agricultural expansion in this region.

Ten thresholds of potential concern have been identified in the G-B catchment (Figure 7). Considered together, the potential consequences of threshold effects across scales or domains (social, economic, biophysical) reveal important interactions among system components that may be influenced by management and governance actions at the focal catchment scale. Crossing any one of the ten thresholds may reduce or increase the likelihood of another threshold being crossed, which in turn could trigger cascading effects for the system as a whole.

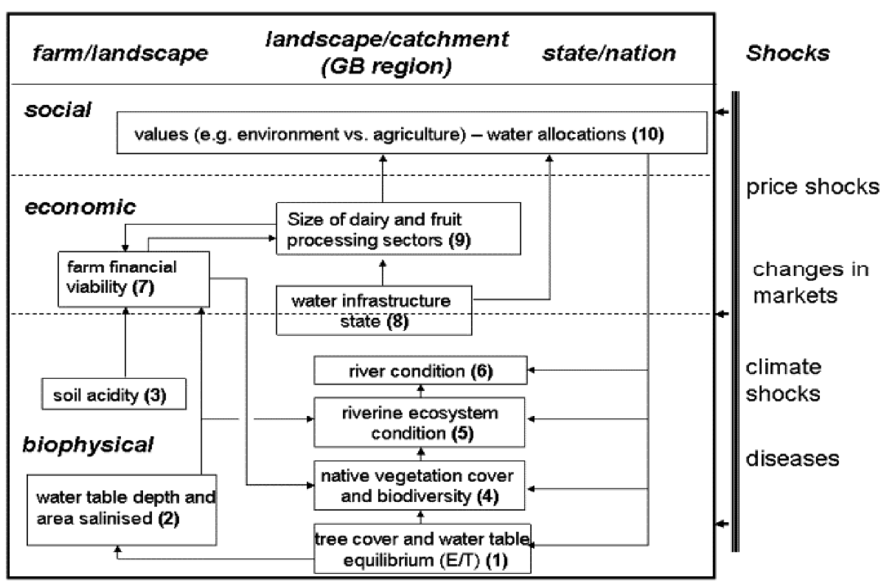


Figure 7. Ten slow variables with thresholds of potential concern in the Goulburn-Broken region of Australia.

Some of the slow variables (e.g., Values) span multiple spatial scales. Expected disturbances, listed on the right-hand side of the diagram, may trigger certain thresholds and have a cascading effect, causing other thresholds to be crossed (represented by arrows linking slow variables). Alternatively, crossing one threshold may under certain circumstances reduce the likelihood of another threshold being crossed. The specific dynamics will be unique to each social-ecological system (Walker et al. 2009).

Assessment

1. Complete the worksheet below by listing the thresholds of potential concern associated with the key slow variables that you identified in Section 2.3. Enter each threshold in the worksheet according to the spatial scale of the variable and whether it is part of the social or ecological domain.

2. For each of the thresholds of potential concern that you include in the worksheet, assign a level of certainty from 1 to 3, where 1 indicates high certainty (quantitative and evidence-based), 2 indicates a medium level of certainty, and 3 indicates a low level of certainty.

3. Referring back to Section 3.1, indicate on the worksheet any significant cross-scale interactions among threshold variables (e.g., draw a dotted line between two threshold variables to indicate a positive interaction where the crossing of one threshold might trigger the crossing of another threshold).

Worksheet 3.2 Thresholds of slow variables and potential interactions.

	Smaller-scale system(s)	*Focal system*	*Larger-scale system(s)*
Social			
Ecological			

Discuss

4. What evidence do you have for the thresholds of potential concern that you have identified?

5. How might you go about improving the level of certainty you have for each of the thresholds that you have identified?

Reflect & Connect

Are there any potential slow-variable thresholds that are vulnerable to the disturbances that you identified in Section 1.3?

Summarize

- List the main thresholds associated with key slow variables and indicate any potential interaction effects, i.e., situations in which crossing one threshold increases or decreases the potential of crossing another threshold.

- Beside each threshold listed, indicate the level of certainty associated with the threshold.

3.3 GENERAL AND SPECIFIED RESILIENCE

A resilience approach calls for assessing both specified and general resilience. “Specified” resilience refers to the resilience "of what, to what” (e.g., the resilience of crop production to a drought). “General” resilience does not consider any particular kind of disturbance (Section 1.3) or any particular aspect of the system that might be affected (Section 1.2).

Resilience to a specific disturbance or event involves identifying a particular threshold effect (Section 2.3) such that the system will not recover its earlier pattern of behaviour if this threshold is crossed. Where there are known or suspected threshold effects, it is clearly necessary to address specified resilience. However, while doing this, it is important to ask, for example, whether it is only the resilience of crop production to drought that is of concern, or the resilience of other ecosystem services to other shocks as well and the resilience of various parts of the social system.

The distinction between these two aspects of resilience is important because if all the attention and resources of management are channelled into managing for resilience to one particular type of disturbance and its associated thresholds, management actions may inadvertently be reducing system-wide resilience. If, for example, a degree of system redundancy is traded off to build resilience to one specific type of disturbance, then the system’s capacity to cope with unexpected or completely novel “surprises” may be diminished. There is therefore a need to consider both general and specified resilience.

Specified resilience relates to the controlling (often slowly changing) variables that are likely to have threshold effects, leading to undesirable and perhaps irreversible changes of system state, which are also referred to as regime shifts. In assessing specified resilience, we ask how these variables will respond to particular kinds of shocks and disturbances and what attributes of the system can be enhanced to avoid exceeding particular thresholds.

General resilience applies to the system as a whole. Given that there may be completely novel shocks, with system responses that are as yet unknown, are there parts of the system that exhibit low or declining levels of those attributes that confer general resilience? Moreover, could actions taken to address any of the specific threshold problems (Section 2.3) lead to unintended losses of general resilience?

Although it is reasonably straightforward to estimate the costs of maintaining general resilience (some form of foregone extra yield or profit), it is much harder to estimate the costs of not maintaining it (because it is nonspecific). For this reason, there is a tendency for general resilience, and even specified resilience, to decline as management pursues goals of increased production efficiency.

Assessment

1. Consider the following attributes that confer general resilience: diversity, openness, tightness of feedbacks, system reserves, and modularity.

   Beginning with diversity, answer the following questions by referring back to the description of your focal system. In particular, what are the main issues? Resilience of what? To what? Develop a working list of system components or areas where low diversity or trends in diversity may be of concern. In which parts of the system is there little or no diversity, which might render the system vulnerable to a loss of function? Are there any trends that reflect declines in diversity?

2. In the same way as for diversity, assess the status and trends of the other general resilience attributes (listed below) by asking similar questions.

   Openness - There is no optimal degree of openness, and either extreme can reduce resilience.

   Reserves - In general, more reserves mean greater resilience, and the trend is often a loss of reserves, both ecological (e.g., habitat patches, seed banks) and social (memory and local knowledge).

   Tightness of feedbacks - There is often a trend towards longer times to respond to signals because of more levels of governance and greater procedural requirements. Ecosystem studies have shown that all thresholds between alternate system states are associated with a change in a critical feedback loop.

   Modularity - There is no optimal degree of modularity, but a fully connected system can rapidly transmit any shock (a disease, a bad management practice) through the whole system. In a system with tightly interacting subcomponents that are loosely connected to each other (i.e., a modular system), parts of the system are able to reorganize in response to changes elsewhere in the system in time to avoid disaster.

Discuss

3. Can you foresee any tradeoffs between specified resilience (Section 1.2, aimed at dealing with the main issues of concern) and general system resilience in the management of your focal system?

4. Which attributes pose the greatest threat to general resilience in your focal system?

Reflect & Connect

Have any of the attributes discussed above fundamentally changed your framing of the main issues or the boundaries of your focal system?

Have your findings in the analysis you just completed caused you to reconsider your earlier ideas about resilience of what and to what?

Summarize

- Summarize the critical attributes of general resilience that should be considered when making decisions about specified resilience in your focal system.
- Report trends in attributes that might influence general resilience in the future.
- Identify any feedbacks that might undermine general resilience in your focal system.

4 GOVERNANCE SYSTEMS

Governance systems are dynamic entities that include a variety of institutions and stakeholders and involve multiple sectors and scales. How these individuals, organizations, rules, and traditions interact determines how people make decisions, share power, and exercise responsibility. Understanding governance is therefore fundamental to understanding social-ecological interactions in your focal system.

History, science, and politics all suggest that joint management and governance processes can be difficult to achieve in practice. To address contemporary natural resource problems, it is therefore important to understand how barriers to collaboration can be overcome. In this section, we focus on two key characteristics of governance systems: ***adaptive governance and institutions*** and ***social networks.*** Both these dimensions of governance systems can inform a clearer understanding of the role of power dynamics and conflicts between stakeholders and their ability either to promote or to undermine the resilience of your focal system.

4.1 ADAPTIVE GOVERNANCE AND INSTITUTIONS

Society is made up of a myriad of rules, some formal, others informal such as cultural practices. These rules guide the ways in which people interact with the ecosystems around them and are referred to as institutions. Formal institutions are codified rules such as constitutions, laws, organized markets, and property rights. Informal institutions include, for example, rules that express the social and behavioural norms of a family, community, or society.

In this section, we consider the roles of both formal and informal institutions within a focal system, as well as the property rights that apply to the resources of concern. These include the laws, policies, and regulations relevant to the main issue(s) and the effectiveness of decision-making, enforcement, and compliance with regard to these issues.

Example: Taboos in Southern Madagascar and forest conservation

In southern Madagascar, informal institutions have historically played an important role in maintaining spiny forest ecosystems. These protected forests provide valuable services such as honey production for the people living around them and cultural services such as connection with ancestors and sacred spaces for burials. The protection afforded to these forests through cultural taboo systems acts as a “sacred fence” which prevents access for harvesting fuel wood and in some cases even for picking flowers. Taboos that prevent access to forests generally involve forests containing tombs, spirits, or honey. Many now consider taboos related to natural resources to be an integral part of “invisible” resource management systems. Since the early 1970s, the spiny forest in southern Madagascar has declined, principally because of clearing for agriculture, cattle herding, timber harvesting, and charcoal production. However, numerous patches of forest are taboo and have remained untouched for sacred reasons, even in the most intensively used areas.

Governance systems that are flexible and decision-making that can respond to changes across scales, as circumstances demand, are especially important because of the tight coupling of social and ecological systems with structures and processes often operating at different spatial and temporal scales. Adaptive governance can enhance resilience by encouraging flexibility, inclusiveness, diversity, and innovation. As illustrated by the example of the Kristianstad Vattenrike Biosphere Reserve, adaptive governance approaches facilitate a number of functions including: interaction across organizational levels, experimentation, new policies for ecosystem management, novelty in cooperation and relationships among agencies and stakeholders, new ways to promote flexibility, and new institutional and organizational arrangements. To illustrate what distinguishes adaptive governance approaches Table 1 summarizes some important differences between conventional freshwater governance and adaptive freshwater governance in Sweden.

Example: Adaptive Governance in Kristianstad, Sweden

A transition to adaptive governance has been extensively documented in the Kristianstad Vattenrike Biosphere Reserve in southern Sweden. The reserve is comprised of wetlands, lakes, rivers, and forests that surround the town of Kristianstad. The ecosystem provides services such as flood control, water purification, and habitat provision as well as cultural and recreational opportunities. In the late 1980s, wading bird populations were in decline, eutrophication of lakes and wetlands was occurring, and traditional uses of the wetlands for haymaking and grazing were becoming increasingly marginalized. Despite international recognition of the wetland, many people viewed the system as something of a wasteland.

By the early 1990s, the management of the area transitioned and a new approach emerged through local initiatives. Flexible and collaborative governance processes now emphasize how people are part of the ecosystem. Kristianstad Vattenrike Biosphere Reserve management today engages with international organizations; national, regional and local authorities; corporations; researchers; nonprofit associations; and farmers and other landowners.

Table 1. Differences between conventional and adaptive freshwater governance in Sweden (adapted from Olsson & Galaz, 2009).

Conventional freshwater governance	*Adaptive freshwater governance*
Stakeholder participation promoted for legitimacy and efficiency of water management	Collective action and network-building promoted to strengthen capacity to deal with unexpected events
Social learning to create consensus around water management initiatives	Social learning is institutionalized to understand system dynamics
Institutions designed to achieve fixed targets	Institutions designed for adaptation to environmental change
Evaluation is unsystematic and applied *ad hoc*	Policy viewed as hypotheses an management as experiments from which to learn
Strategies to deal with uncertainty are absent	Strategies to tackle uncertainty and complexity are a fundamental aim
Emphasis on solutions to achieve fixed water quality and quantity targets	Emphasis on solutions to reduce vulnerability and strengthen capacity to respond and adapt
High reliance on models as a base in river management plans	Models in collaborative processes important to understand behaviour of freshwater systems and to identify critical thresholds
Institutional homogeneity promoted to secure administrative equality	Institutional diversity encouraged to promote innovation and reduce vulnerability
Multilevel water governance encouraged for legitimacy and efficiency with regard to fixed targets	Multilevel governance promoted to secure local ecological knowledge, reduce vulnerability, and strengthen capacity

Assessment

1. What key formal and informal institutions have a bearing on decision-making within your focal system? Do any of these enhance or constrain flexibility to address issues as they arise? Keep in mind the key issue(s) on which you are focussed.
Enter this information in the worksheet provided.

2. At what levels are key decisions being made that affect the focal system and the main issue(s) of concern? Are these levels appropriate given the issue(s) of concern in your focal system?
Enter this information in the worksheet provided.

3. Is rule compliance and enforcement effective? Rules and enforcement may be either formal or informal, but those in charge of enforcement must be seen as legitimate by the resource users.
Enter this information in the worksheet provided.

Worksheet 4.1

Key formal and informal institutions			
	List of institutions	***Enhance flexibility (Yes/No)***	***Restrain flexibility (Yes/No)***
Main issue 1			
Main issue 2			
Overarching			

Level of decision-making			
	Local, municipal, provincial, national, regional	***Appropriate given ecological processes? (Yes/No)***	***Suggested improvements***
Main issue 1			
Main issue 2			

Rule enforcement and compliance		
	Is it effective? (Yes/No)	***Suggested improvements***
Main issue 1		
Main issue 2		

Mapping power relations and conflicts				
List of Stakeholders	***Formal power (strong, intermediate, weak)***	***Informal power (strong, intermediate, weak)***	***Conflicts with other stakeholders? Specify.***	***Conflict resolution mechanisms in place?***

Discussion

4. Discuss the differences in power and the ability to influence decision-making among stakeholders (refer to Section 1.2). Consider both formal and *de facto* power. Formal power is exercised through policymaking and other formal decision-making structures. In many parts of the world, formal power is less effective at local levels where local people possess *de facto* power because of their proximity to and use of resources. Informal institutions (e.g., homeowners' associations, fishing clubs, local norms, or taboos) may exert much influence over the use of resources.

5. Are conflict resolution mechanisms in place to deal with power inequalities and differences in values, interests, and perspectives? Is there a general willingness to engage in collaborative decision-making?

6. Is decision-making concentrated within a single group or institution, or is a diversity of institutions accepted by stakeholders?

Reflect & Connect

Given the interactions within and across scales identified in Sections 2 and 3, is the current governance system geared toward responding to ecological changes at the appropriate scales? If not, how might it be improved?

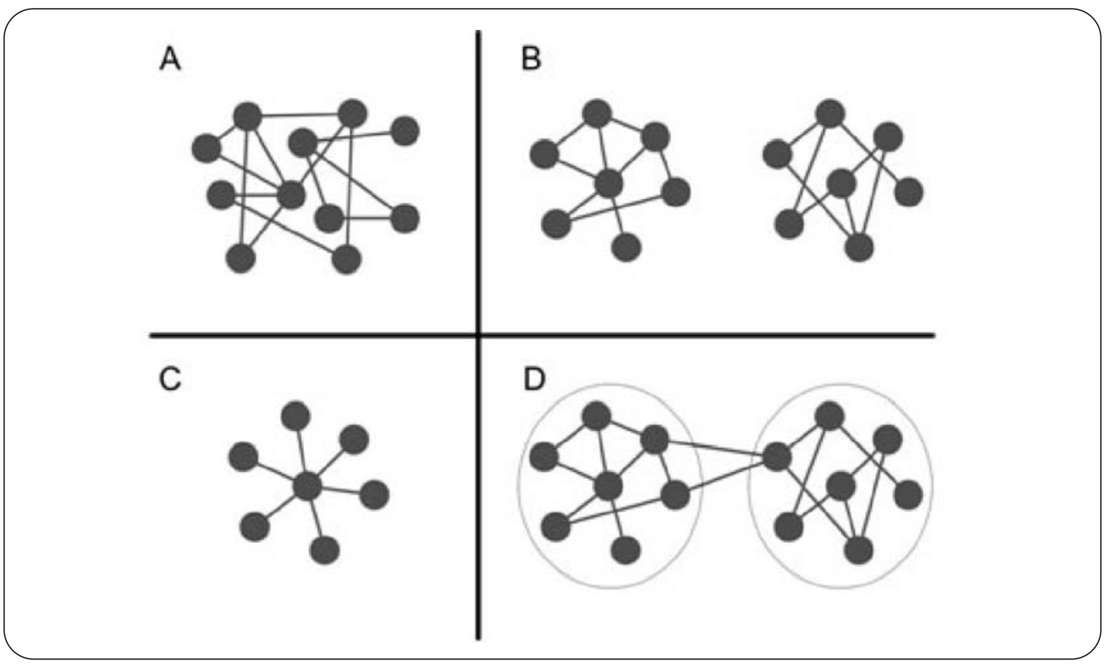
Summarize

- Summarize how decision-making is taking place, including at what scale(s).
- Summarize key differences in power between decision-makers at different scales.
- Summarize any conflicts.
- Summarize the degree to which flexibility is built into the current governance system.

4.2 SOCIAL NETWORKS AMONG STAKEHOLDERS

Managing for resilience requires cooperation among stakeholders in the social-ecological system. This cooperation can be facilitated by an understanding of the social relations among the stakeholders by examining social networks. The structural characteristics of a given network can influence system dynamics and management outcomes by for example, facilitating or impeding processes such as information sharing, access to resources, and collaboration opportunities. There is no optimal structure. Different network characteristics facilitate different processes that are important at different stages of a governance process. Depending on the specific challenges facing a social-ecological system, some characteristics may be more beneficial than others for influencing the adaptive capacity of the system (Figure 8).

Figure 8. Schematic presentation of some archetypical network structures.
(A) represents a network without any clearly distinguishable subgroups, whereas (B) presents a network that is divided into two isolated subgroups. (C) represents a highly centralized network), and (D) represents a network with two distinguishable groups which are connected by two bridging ties.



EXAMPLE: Social Networks and Governance of Urban Ecosystems in Stockholm, Sweden (Ernston et al. 2008)

The National Urban Park near the centre of Stockholm, Sweden has continued to support relatively high levels of biodiversity and a variety of ecosystem services on a time scale of centuries. However, by 1990, escalating land-use pressure and new land development plans catalyzed a social movement called Ecopark, comprised of 62 civic organizations that sought to protect the park. These diverse groups, ranging from gardeners to boaters to nature conservationists, all played a role in obtaining legal protection for the park in 1995. Despite the park's legally protected status however, development remains a threat, and the ways in which the park is used and the intensity of use maintain a need for the movement.

The Ecopark movement, while having achieved some success at collective action, does not represent a homogeneous set of interests. The relationships among the various stakeholder groups can potentially hinder collaborative management in ways that can be explained in part by the network's core-periphery structure.

At the centre of the Ecopark network are a small number of core and semi-core organizations, whose main interests are in conservation, and who have purposefully developed and nurtured political ties to authorities. Around these is a large set of peripheral organizations that consists of groups that actively use the park on a regular basis. This structure is believed to play an important role in protecting the park, in part because of the diversity of interests represented, but also because of the links that the core organizations have to higher-level decision makers. At the same time, however, this network structure may also constrain collaborative ecosystem management. This is partly due to the differences between the core and peripheral groups in terms of how they value the park, i.e., for nature preservation versus for active use and enjoyment. In addition, some of the peripheral groups that possess local ecological knowledge of the park have not always been included in collaborative activities. In this case, the use of social network analysis provided insight into how values as well as knowledge are important components of collaborative ecosystem management and revealed an opportunity for improving management by empowering user groups on the periphery of the network.

Assessment

1. Mapping the social network in your focal system. Ideally, a network is mapped by asking each and every actor about his or her relations with others and then creating the complete network be merging all the reported relations. In practice, however, one must often rely on key informants to map the complete network. Similarly, one may choose to map contacts between groups rather than between individuals. A number of software tools are available to assist in mapping social networks. You may choose to construct a simplified sketch of the social network based on available information (see Section 1.2) or to conduct a more thorough analysis using social network analysis methods documented elsewhere.

2. Once a social network has been mapped, a number of basic analyses can provide insight into how the structure of the network may facilitate or hinder governance efforts. Here we focus on: the ***number of relations*** between actors, the degree of ***centrality*** of actors in the network, and the existence of ***cohesive subgroups.*** The archetypal network structures associated with each of these are shown in Figure 8. In the focal system, are there any highly central actors in the network? Are subgroups present? If so, how isolated are these subgroups?

3. Are there key people or groups of people who are not connected to others? How might this affect the potential for solving resource conflicts, reaching consensus on management strategies, etc.?

   To what extent do highly central and potentially influential actors represent the views and interests of the other stakeholders? If centrality is a strong feature of the network, is it a source of social cohesion or a potential barrier to achieving it?

Are there any actors in the network that link otherwise separated groups and do they represent bridges or barriers to collaborative governance?

Are there multiple groups of actors, or are all actors connected within one large group? What might be the implications of this characteristic of your network in terms of achieving social cohesiveness versus maintaining specialized knowledge and expertise?

Are there isolated subgroups that might pose a barrier to social cohesion?

Discuss

4. Consider the ways in which individual actors (or groups) may use their position in a network to influence the natural resource governance process in your focal system.

5. Consider the ways in which central actors may be benefiting more peripheral actors if they function as information hubs which collect and coordinate information, innovations, and new ideas from the periphery of the network.

6. To what extent does the network "hang together" instead of being divided into separate subgroups?

7. Consider any linkages between stakeholders operating at different hierarchical or geographical scales in your focal system and how that might benefit collaborative governance processes.

Summarize

- Summarize the social networks in your focal system. Are they centralized, are there cohesive subgroups, and are there key actors who are not connected to other key actors?

- List any central actors and their potential roles as bridges between actors.

- List any activities that might increase connectivity between actors and subgroups, and also the potential risks associated with these activities.

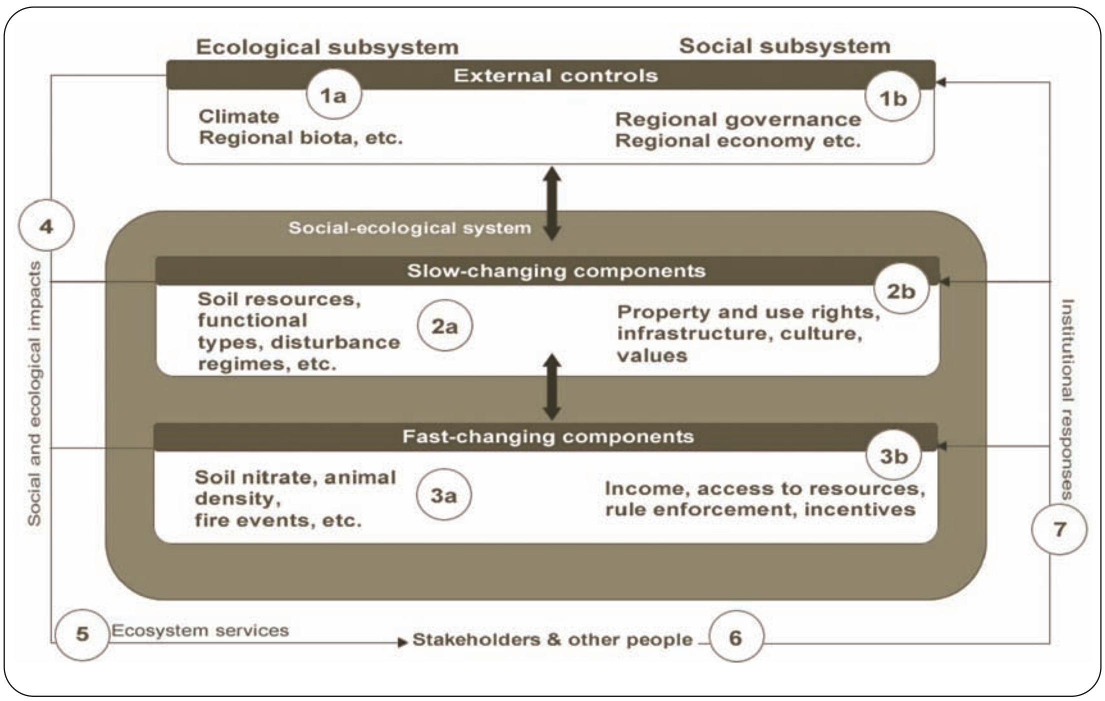
5 ACTING ON THE ASSESSMENT

5.1 SYNTHESIZING THE ASSESSMENT FINDINGS

This resilience assessment framework guides a process for building knowledge and understanding of the interactions, dynamics, and potential thresholds of concern for a particular social-ecological system. The information gathered and recorded throughout the assessment is used as a basis for developing two conceptual diagrams that help to synthesize the assessment findings thus far. The first of these diagrams shows a model of the social-ecological system that is the focus of the assessment. A generalized version of an SES model from the introduction is shown for easy reference in Figure 10. The synthesis begins by reviewing the assessment summaries completed at the end of each section and using the information therein to construct a conceptual diagram of the focal system. Guiding questions link key corresponding sections of the assessment with the model's component parts. It should, however, be noted that the general SES model in Figure 10 is presented to help guide development of your own model of your focal system. Alternative formats of or variations on this SES framework may be more appropriate for different types of systems.

Figure 10. General conceptual model of a social-ecological system.

The main parts of the conceptual model are numbered as 1-7 for easy reference and linking to the specific guiding questions in Table 2.



Building the conceptual model is an iterative process and will likely require several rounds of editing and fine-tuning. The set of questions presented in Table 2 is used to guide the construction of the SES model. Note that the process of synthesizing the assessment and constructing the diagrams is not a rigidly formulated process. Rather, you should draw upon your own understanding and insights gained throughout the entire assessment. The synthesis will be unique for each system and will yield unique sets of follow-up questions, proposed interventions, and strategies for conserving or building resilience.

Table 2. Guiding questions for constructing a conceptual model of a social-ecological system.
Each number in brackets and italics corresponds to a location in the general SES model shown in Figure 10.

Refer to Section	*Guiding questions for reflection*
1.1	What are the environmental and social impacts of the main issue(s) that was identified? *[4]*
1.2	Considering the main resource use(s) that is central to the main issue, what are the key ecological components of the natural resource that change relatively slowly over time (e.g., trees are a slow variable relative to fire or pest invasions)? *[2a]* What are the key ecological components of the natural resource that change relatively fast over time? *[3a]* Who are the key stakeholders and what role(s) do they play in the system? *[6]* What are the main ecosystem services that are most important to stakeholders and others? *[5]*
1.3	What is known (in summary) about the main disturbance regime(s) of the system? *[2a]* What are the main disturbance events? *[3a]* What are the social and ecological impacts of disturbances in the system? *[4]*
1.4	What are the larger-scale external controls that interact in a significant way with the focal system? *[1a & 1b]* Are there smaller nested systems that affect any of the faster-changing components of the focal system? *[3a & 3b]* How do current institutional responses differ from those in the past? *[7]*
2.1	Referring to the adaptive cycle diagram developed in Section 2.1, are there key system components that change relatively slowly or quickly and that should be added to the SES model? *[2a&b, 3a&b]* If the adaptive cycle exercise revealed any new insights into social and ecological impacts or institutional responses, add these to the model. *[4 & 7]*
2.2	The rule of hand challenges the analyst to reduce the number of key variables that define a system state. Without oversimplifying, are there components of the SES that you might want to remove or set aside from the model? *[2a&b, 3a&b]*
4.1	Is decision-making taking place at larger scales (external to the focal system) that significantly impacts your focal system? *[1b]* Are there power dynamics in the social domain of your focal system that significantly influence how the system is structured and how it functions? *[2b, 3b, 7]*

Part B of the synthesis - Thresholds and Interactions

A second diagram is then constructed using the template in Figure 11 and is structured around potential critical thresholds of the main slow variables in the system (see also Figure 7 in Section 3.2). The slow variables are represented at multiple scales, and the lines connecting variables highlight potential interactions among system thresholds. In constructing this diagram, it will be necessary to refer back to the summary assessment information gathered in previous sections. As in the example of the Goulburn-Broken catchment in Section 3.2, the thresholds and interactions diagram is meant to illustrate how crossing one threshold can trigger the crossing of other thresholds, thus creating a cascading effect.

The general template for constructing the thresholds and interactions diagram in Figure 11 corresponds to the questions in Table 3 that link to the assessment summaries. These questions also aim to assist in identifying and highlighting components of the SES that degrade or enhance general system resilience (by considering cross-scale interactions) as well as specified resilience to known disturbances or pressures relative to the key issues that framed the assessment. As with the previous set of guiding questions, they are meant to serve as a flexible guide to constructing a diagram that illustrates thresholds of potential concern in your focal system and how these slow-variable thresholds might interact in response to specific disturbances.

Figure 11. Template guide for a thresholds and interactions diagram.

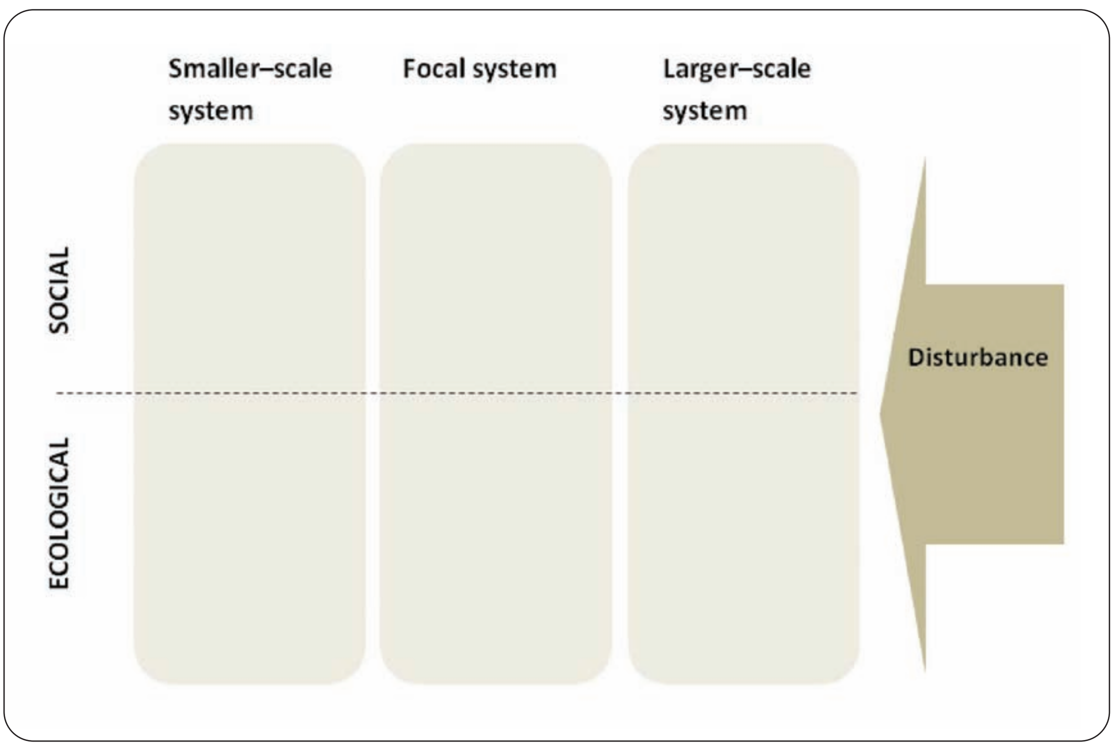


Table 3 - Guiding questions for constructing a thresholds and interactions diagram.

Refer to Section	*Guiding questions for reflection*
2.2	What are the key slow variables associated with thresholds that are (or would be) responsible for a shift between the alternate states that you identified previously? At what scale do these slow variables operate?
2.3	Reviewing your list of potential thresholds of concern, identify the thresholds associated with slowly changing variables. If your list of slow-variable potential thresholds includes primarily social or primarily ecological variables, challenge yourself to consider additional potential thresholds in the ecological domain. Are there any thresholds that you may have overlooked because of the level of expertise of those conducting the assessment? What are the system disturbances identified earlier that might move the system closer to a threshold? Indicate on the thresholds and interactions diagram any potential interactions that you identified previously.
3.1	Do any of the cross-scale interactions that you identified previously in Section 3.1 involve the slowly changing variables included on your draft interactions and thresholds diagram?
3.2	Review your list of thresholds and interactions from Section 3.2 and apply this information to a full revision of your diagram thus far. You may want to codify the thresholds to indicate the level of certainty associated with each threshold or to vary the weight of the interaction lines based on your understanding of the likelihood or impact of specific interactions.
3.3	Are there potential slow-variable thresholds that you previously identified with respect to general system resilience?
4.0	What role does the governance of your focal system play in the potential for crossing or avoidance of slow-variable thresholds in your diagram?

5.2 RESILIENCE-BASED STEWARDSHIP

Specific management interventions and the development of strategic plans in response to a resilience assessment depend upon an understanding of system dynamics and key variables that are generally unique to each social-ecological system. The synthesis described in the preceding section attempts to distil the key variables and dynamics of the SES to provide insight into resilience-building options. Although the array of options available will normally be unique to each system, general guidelines that are applicable to most SES can be stated for promoting resilience-based ecosystem stewardship.

In the context of resilience-based stewardship, the overarching goal is to sustain the capacity of the SES to provide benefits to society. The questions of which benefits and to whom the benefits flow are fundamentally important and demand effective stakeholder participation. Similarly, management efforts that focus on critical slow variables and system feedbacks, such as those identified in the conceptual models described in the previous section, reinforce a shift from steady-state resource management to ecosystem stewardship. The latter approach involves a change in the role of the resource manager to one of engaging stakeholder groups to respond to and shape how a system changes over time, thereby maintaining sufficient flexibility and future options.

Table 4 lists four categories of stewardship strategies to enhance SES resilience and offers examples of strategies in each category. Using the same categories, specific strategies can be drafted based on the resilience assessment findings, which can provide a basis for taking the next step of building on the assessment.

Table 4. Examples of stewardship strategies to enhance social-ecological resilience (Chapin et al., 2009).

Foster biological, economic, and cultural diversity • Prioritize conservation of biodiversity hotspots and locations and pathways that enable species to adjust to rapid environmental change • Retain genetic and species diversity that are underrepresented in today's landscapes • Exercise extreme caution when considering assisted migration • Renew the functional diversity of degraded systems • Foster retention of stories that illustrate past patterns of adaptation to change • Subsidize innovations that foster economic novelty and diversity
Foster a mix of stabilizing feedbacks and creative renewal • Foster stabilizing feedbacks that sustain natural and social capital • Allow disturbances that permit the system to adjust to changes in underlying control variables • Exercise extreme caution in experiments that perturb a system larger than the jurisdiction of management
Foster social learning through experimentation and innovation • Broaden the problem definition by learning from multiple cultural and disciplinary perspectives and facilitating dialogue and knowledge co-production by multiple groups of stakeholders • Use scenarios and simulations to explore consequences of alternative policy options • Test understanding through experimentation and adaptive co-management • Explore system dynamics through synthesis of broad comparisons of multiple management regimes applied in different environmental and cultural contexts
Adapt governance to changing conditions • Provide an environment for leadership to emerge and for trust to develop • Specify rights through formal and informal institutions that recognize needs for communities to pursue livelihoods and well-being • Foster social networking that bridges communication and builds accountability among existing organizations • Permit sufficient overlap in responsibility among organizations to allow redundancy in policy implementation

5.3 TIME FOR TRANSFORMATION?

Is transformation of the focal system desirable or necessary? A transformation is considered desirable or necessary when existing ecological, economic, and social structures become untenable. Important considerations regarding to whom transformation is desirable must also be addressed.

A ***transformation*** is said to have taken place when there is a change in the key components that define a system and in the relationships between cycles of change and feedbacks across scales. The shift from sheep farming on a single farm to wildlife-based ecotourism that involves joint enterprises by combining properties to operate at larger scales is an example of transformation.

Previous sections identified individuals and organizations that have key leadership roles (Section 1.2), characterized their relationships and the ways that stakeholders work together (Section 4.2), and identified institutions (both formal and informal) in the focal system (Section 4.1). In this section, we examine the capacity of the system to respond to change by identifying various forms of capital in the system and devising a plan to build capital where it is needed. Although this section provides some guidelines based on how transformations have taken place in other systems, it is generally difficult to "control" a transformation in a focal system. Therefore, it becomes necessary to consider the implications of initiating transformational change and the potential that the process may be hijacked by other interests.

Example: A transition toward ecosystem-based management in the Great Barrier Reef, Australia

The Great Barrier Reef (GBR) Marine Park in Australia covers 344,000 km2, an area almost the size of California. The Reef itself generates essential ecosystem services and contributes AU$6.9 billion annually to the Australian economy, 85% of which comes from the tourism industry.

In 1975, the Australian federal government enacted the Great Barrier Reef Marine Park Act in response to public concerns over threats to the reef from oil drilling, mining, and unexplained outbreaks of coral-eating starfish. The GBR marine park is a multiple-use park that allows a range of uses based on spatial zoning, including no-take zones. At the state level, the Great Barrier Reef Coast Marine Park was created to protect tidal lands and coastal waters. The State Park complements the federal GBR Marine Park by adopting similar zone objectives and entry and use provisions. This federal–state cooperation is important for enabling ecosystem-based management of the region.

As scientific information accumulated, it became apparent that the Great Barrier Reef was becoming degraded, primarily from sediment runoff from land, overharvesting, and global warming. Data gathered in the 1980s and 1990s revealed rapid growth in human population, land clearing, coastal development, tourist visits, and fishing pressure.

It became clear that the initial level of protection did not adequately protect biodiversity within the GBR Marine Park or ensure that the entire ecosystem remained healthy, productive, and resilient. In the late 1990s, scientists and reef managers became aware that many biological communities, such as inshore and deeper habitats, were poorly represented in existing no-take zones. They also realized that connectivity of larvae and other poorly understood interactions between reef and non-reef habitats were important to maintain the resilience of the entire ecosystem.

Therefore, in 1998, the GBR Marine Park Authority initiated a major rezoning of the marine park called the Representative Areas Program (RAP) to increase biodiversity systematically by protecting representative examples of each type of habitat within a network of no-take areas. Following extensive public consultation, a Revised Zoning Plan was developed that increased the percentage of no-take areas in the GBRMP from 5% to 33%, including at least 20% of each of the 70 bioregions. The new zoning plan was passed into law in 2004.

The transition of the GBR and implementation of the new zoning plan involved five general strategies in the GBRMPA: (i) internal organizational changes, (ii) bridging science and policy, (iii) changing people's perceptions, (iv) facilitating public consultation and participation, and (v) gaining political support. Table 5 summarizes the general strategies used, the actions taken, and some examples of barriers to change. A common feature of the GBR Marine Park Authority's strategy was anticipating and addressing potential barriers to the implementation of an ecosystem-based approach.

Table 5. General strategies, actions, and examples of barriers in the transition toward ecosystem-based managed in the Great Barrier Reef (modified from Olsson et al. 2008)

Strategies	*Actions*	*Examples of barriers to change*
Making internal organizational changes	-Establishing Senior Managers' Forum and regional teams -Clear and transparent leadership at all relevant levels -Communicating vision and goals	-Resource constraints -Lack of innovation, direction, shared vision, engagement, trust, leadership, cross-sector cooperation, and communication
Bridging science and policy	-Drawing on existing networks of scientists, managers, and industry to promote dialogue -Forums for synthesizing knowledge -Communicating vision and goals	-Science is fragmented -Scientific uncertainty -Different perceptions of scientists and managers and resulting lack of trust
Changing public perceptions	-Clear, simple, tailored information from a communication professional -Visualizing the entire GBR as an interconnected ecosystem -Communicating an urgent need for conservation	-Different levels of knowledge and interests among stakeholder groups -Low awareness and understanding of problems, threats, and ecological interactions
Facilitating community participation and public consultation	-Building trust with communities through personal interactions and regional teams -Community information sessions -Recasting problems as opportunities -Regular updates	-Conflicting views among key actor groups, misinformation -Outreach to local communities difficult -Lack of leadership and trust
Gaining political support	-Preparing for change: staff expertise, timing actions, information availability -Briefing key players and allying with other key actor groups -Polling to leverage and monitor public opinion	-Change of people in power -Lack of support from key politicians -Zoning plans can be stopped -Opposing views

Discuss

If your case merits a consideration of transformation (e.g., if it is heading toward a critical threshold and if decision-making is centralized and ineffective), consider the following issues:

- If the focal system is heading toward a threshold of potential concern, how is the general resilience of the system likely to be affected by a transformation in governance and management?
- In whose interests might a transformation be, and who might be negatively affected? Because there are many possible directions for a transformation, consider this question in the context of potential alternative future scenarios.

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

Action

Consider the strategies, actions, and barriers experienced in the Great Barrier Reef example summarized in Table 5 and try to develop strategies applicable to the focal system.

The strategy development process may be facilitated by working through the following:

- Identify trust-building opportunities in your system and devise a plan for implementation.
- Devise a plan for improving knowledge sharing among stakeholders and formalizing mechanisms for input from all levels of governance.
- Consider the following ways to build capital and trust and discuss how you can encourage these practices in your focal system: 1) making strategic investments to secure ecosystem goods and services; 2) incorporating ecological knowledge into institutional structures; 3) creating social and ecological networks; 4) combining different forms of knowledge for learning; 5) providing incentives for stakeholder participation; 6) identifying and addressing knowledge gaps; 7) developing expertise.

Completing the resilience assessment and implementing adaptive management

A resilience assessment is most effective when it becomes integrated into strategic plans and management processes. Adaptive management is an approach captured in the phrase 'learning by doing'. It is a learning-based approach to resource management that views policies as guesses or hypotheses, and actions as ways of testing those guesses. The main point of an adaptive assessment is to try to define what is known and what is not known about various management issues. It makes explicit the assumptions underlying management. Management actions can then be structured to test these assumptions (system understanding), while solving management issues. In doing so, adaptive assessment attempts to fill the gap between knowledge and action. The reader is encouraged to develop an adaptive assessment and management program with the aid of key references provided.

The framework presented in this workbook is designed for repeated updates and fine-tuning. As a system evolves or new issues emerge, it may be helpful to revisit the assessment at regular intervals. The conceptual SES model as developed is a tool for achieving long-term, sustainable environmental services. The flexibility, variability, and diversity that confer resilience to the focal system are also the reasons to be sensitive to changes in system dynamics over time. Revisiting the broad questions of the resilience assessment on a regular basis will ensure that the adaptive conceptual model can function well to achieve management goals and to underpin strategies that support system resilience and integrity.

Visit the Resilience Alliance website www.resalliance.org for more resilience assessment resources.

GLOSSARY

Adaptive cycle - A sequence of four commonly occurring phases of change in complex systems: exploitation, conservation, creative destruction, and renewal (also referred to as r, K, omega, alpha).

Adaptive governance - Institutional and political frameworks designed to adapt to changing relationships between society and ecosystems in ways that sustain ecosystem services.

Capital - Those elements in a mature system that make possible the extended existence of that system within its larger context.

Disturbances - External stresses and shocks that disrupt ecosystems, communities, or populations, change substrates and resource availability, and create opportunities for new individuals or colonies to become established.

Ecosystem services - The benefits derived from ecosystems, including provisioning, regulating, cultural functions, and supporting services.

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

Governance - The interactions of diverse public and private actors, their sometimes conflicting objectives, and the instruments chosen to steer social and environmental processes within a particular policy area.

Governance systems - Dynamic systems that include a variety of institutions and stakeholders and involve multiple sectors and scales.

Institution - A set of rules and norms that guide how people within societies live, work, and interact. Formal institutions consist of codified rules such as constitutions, organized markets, and property rights. Informal institutions consist of the rules which express the social and behavioural norms of a family, community, or society.

Learning - Involves the comparison of mental models with data and information from the world. Social learning is learning that occurs when people engage with one another, sharing diverse perspectives and experiences to develop a common framework of understanding and a basis for joint action.

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

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

Resilience - The capacity of a system to absorb disturbances and reorganize while undergoing change so as to retain essentially the same function, structure, identity, and feedbacks.

GLOSSARY (CONTINUED)

Scale - The spatial and temporal frequency of a process or structure. Scale is a dynamic entity. For the purposes of a resilience assessment, the focal scale of a social-ecological system of interest is usually determined from among landscape/local, subcontinental/subregional, continental/regional, and global scales over a specified period of time.

Social-ecological system (SES) - An integrated system of ecosystems and human societies with reciprocal feedbacks and interdependence. The concept emphasizes the "humans-in-nature" perspective.

Social network - A map of social relations among individuals or organizations.

Stakeholder - Any individual or organization that can affect or be affected by the management of the resources in question.

System state (regime) - The identifiable configuration of a system defined by its structures, functions, and feedbacks.

Threshold - A breakpoint between two regimes of a system.

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

Transformation - A change that results in a fundamentally new system.

Vulnerability - The propensity to suffer harm from exposure to external stresses and shocks.

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APPENDIX 1 – ECOSYSTEM SERVICES

Ecosystem Service Type	***Examples of Ecosystem Services***
Provisioning Products and goods obtained from ecosystems	Freshwater, Timber, Fiber, Capture fisheries, Crops, Livestock, Aquaculture, Wild foods, Wood fuel, Genetic resources, Biochemicals
Regulating Benefits obtained from ecosystem processes	Water purification, Erosion regulation, Air quality regulation, Carbon sequestration, Flood protection, Disease regulation, Pest regulation, Pollination, Natural hazard regulation, Local climate regulation
Cultural Non-material benefits from ecosystems	Spiritual values, Aesthetic values, Recreation opportunities, Tourism, Identity
Supporting	Soil development, Wildlife habitat, Primary production, Nutrient cycling

Modified from MA 2005.