Assessing and managing resilience in social-ecological systems: Volume 2 supplementary notes to the practitioners workbook

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Resilience Alliance

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Part I:
The Resilience of What, to What?

The next 4 steps were developed to begin to link concepts of resilience with the management or resource issues of concern. This is done by defining key attributes of the system (the resilience of what) and defining some of the disturbances and processes that influence that resilience (the resilience to what).

1.1
Bounding the System: Describing the Present

Before beginning any assessment, it is useful to determine, at least approximately, the boundaries of what is being evaluated. Boundaries define what is in a system, and what is outside of the system. Maps, for instance, may outline countries or states (political and economic boundaries), lakes or rivers (ecological boundaries), fishing zones (management rule boundaries), or indigenous lands (cultural boundaries). Just as systems are bounded in space, they are also bounded in time. That is, resource issues are analyzed and actions taken within certain time frames. Planners often refer to time horizons, which is another way of expressing boundaries in time.

The area defined by spatial boundaries can be small or large, fixed or variable, depending upon a given problem or issue. For example, consider someone who is concerned with a lake. The shoreline of the lake is a natural boundary between water and land. The person may own a portion of land and have certain property rights (to build a house, to cut trees, to build a dock, etc.) the person may have access to fish in the lake, but may or may not own any rights to the water in the lake. At larger areas, neighbors may comprise a set of lake users. At even larger scales, the person may be part of a villages or community surrounding the lake, which has a broader spatial boundary. And so on.

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

Imagine that one day (or, more likely, gradually over time) the clear lake with good fishing begins to turn green, and fish populations begin to decline. To begin to understand what has happened, one would make some choices to start to bound the problem. Need I look only at my neighbor, the village, or the village and its surrounding uplands? Is it just this lake, or a chain of lakes? Each one of these would have a different area and spatial boundary, and each one would relate to a different assumed cause for why the lake turned green. Similarly, once the cause of the green lake was determined, one might expand or contract the spatial boundary in looking for a solution. Even if there is a chain of lakes in trouble, can a solution be devised for this lake at the village level? If the problem is with land use in the surrounding rural system, what state or federal agencies need to be involved? Frequently, the scale at which the problem is emerging and the scale at which it needs to be solved differ from each other.

Experience indicates that there is no easy way of defining problems in space or time. The best approach is to start out with best guesses of these bounds, then refine or change as needed. You will make your initial assessment of boundaries in the assessment following this chapter, but you should consider revisiting that assessment in subsequent sections if need be.

Simplifying the Complex: What to include, what not to include

Much of the dynamics of complex systems can be traced to a handful of variables

Once one has established the boundaries for thinking about a problem, what within those boundaries does one include? Everything? That would seem hopelessly complex—we probably needn't know about what our neighbors had for dinner or when the village fair is to be held in order to understand our problem. On the other hand, one can imagine needing to know about agricultural fertilizer practices (which can lead to green lakes or more technically, lake eutrophication), the chemicals already in the sediments of the lake, the reproductive strategies of the fish in the lakes, the recreational behavior of boaters and fishers, the flows of water between lakes, or between lake and sediments, etc. As you might imagine, the assessment can get complicated very quickly.

Incorporating too much detail can hamper progress towards understanding the problem and defining a solution. Too little detail, or too narrow a scope of study, however, can lead to incorrect solutions. The manager in charge of stocking a lake, for instance, may only concern herself with the biology of the fish—how many fish should I introduce and of what age if I want so many fish next year? The manager in charge of issuing fishing permits may concern himself more with the economics of the situation—how much revenue can my community generate from permits, what is an efficient way to distribute them, what enforcement mechanisms are required? If the two managers never talk, they risk failure of the lake fishery, because there will be no understanding of how the stocking protocols affect the fishing behavior of the fishermen, and/or no understanding of how fishing strategies affect the age structure and breeding potential of the fish population. When one considers the potential effect of other species of fish on both the biology of the target species and on the behavior of fishermen—or that others using the lake for other types of recreation can also influence the lake fishery—the situation becomes even more complicated.

In many analyses of natural-resource management—examinations of what went right and what went wrong—one dominant pattern emerges. When management fails it is frequently because managers have considered too much detail for a narrow aspect of the system, and too little detail for all the rest. The component of detailed scrutiny usually depends on the training of the manager—a biologist will study the biology in great detail, an economist the economics, and so on. The other parts of the system are understood only shallowly, or not at all.

Social-Ecological Systems

Management fails when managers consider too much detail for one part of the system, and too little detail for the rest

One of the early insights of resilience theory, then, was the need to examine coupled social-ecological systems. It's not enough to understand the biology in great detail if one doesn't also understand the dynamics of the markets that drive resource use, or the cultural attachments people may have to certain ways of doing things. A detailed economic analysis will be incorrect if it doesn't contain information on the biological limits to renewing or producing certain resources.

Nor is it enough to have a team of researchers or managers, each of whom understands a particular component—soil quality, local markets, traditional practices, national environmental regulation—in great detail. In the past couple of decades, a new kind of science focused on *complex systems* has revealed that understanding the component pieces of a system doesn't guarantee understanding the behavior of the system as a whole. We know a lot, for instance, about various parts of the human brain and how it controls emotion, processes sensory information, stores memories. But mastering each of these pieces still doesn't tell us about the complex behaviors of an individual. We need to study the individual as a whole person—not as a collection of pieces—in order to understand his or her behavior. And even then what we really need to do is understand how that individual is influenced by her family, her peers, her community, and her culture.

Mastering that level of understanding isn't easy, of course. None of us is equipped to be expert in all fields. But effective management of natural resources *requires* that one reach out well beyond one's area of training or interest to encompass ecological, social (primarily political, cultural and institutional), and economic domains of the system. The *ecological* components would include all of the non-human living organisms, as well as the physical and chemical features that help determine their habitat or environment, and the interactions of the living and non-living components of that system (such as soils, topography, etc.). The *social* component includes the political agencies and institutions, cultural traditions, the formal legal systems, and the informal rules governing people's behavior, among other things. It can also include the technology or technological development that can be brought to bear on a problem. The *economic* component includes the formal (frequently markets and formal property rights) and informal (e.g., barter systems) societies have developed for allocating resources and exchanging goods. We call each of these components a *domain*. Throughout this working book, therefore, we will concentrate on at least these three domains, recognizing that each of them also includes many components. (You may find it helpful to also introduce other domains in your analysis and should feel free to do so.) When we refer to a *social-ecological* system, we are referring to a system comprising at least the three domains of social, ecological, and economic (and use social-ecological as a manageable label).

Mastering a more holistic understanding of the system also means respecting the knowledge that those with different training and perspectives bring to the table – including those who may have no formal academic training, and whose capacity to see the system as a whole may be greater as a result. And it is exactly that – seeing the system as a whole – not the sum of parts, but the union of parts, that will provide the vantage point from which solutions may be sought. Thus, throughout the assessments that follow in this working book, we encourage you to consider at least these three domains—ecological, economic, and social as well as their interactions. Focusing only on the ecological, or economic, or social domains will not allow an effective resilience analysis.

Building resilience requires integrating ecological, social, and economic perspectives.

The activities that follow are intended to help define the system, and its key ingredients. We will call this whole agglomeration—the natural resource, the people managing it and using it, the institutions governing access, commercial and non-commercial values, the ‘focal system’. We’ll be evaluating various aspects of this system in subsequent chapters.

Fundamentals: What is a Social-Ecological System? A system is a group or set of connected components that comprise a unified object. Systems can be living, such as the human body, which is made up of genes, cells, tissues and organs. Systems can have living and non-living components, such as an ecosystem, which is made up of plant, animal (biotic), water, air, and nutrient (abiotic) constituents. Social-ecological systems have strongly coupled ecological and societal components. For example, in many coastal fishing communities, marine resources are usually tightly integrated with the local economy, culture, and political dynamics. In other social-ecological systems, ecological components may include grasslands, reefs, forests, lakes, wetlands, or other sets of natural resources. The social components may be the individuals, organized groups, and institutional rules used to guide interactions with the ecosystem. These actions and interventions are developed to manipulate ecological systems to receive goods and services for the benefit of humans.

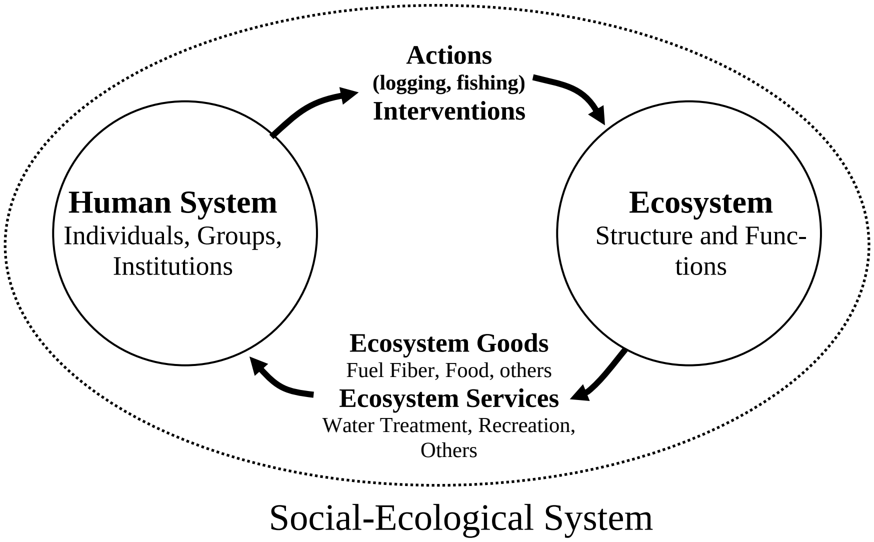


Figure 1: Conceptual diagram of elements of a social-ecological system. Human systems, comprised of individuals, groups, networks and institutions (rules, regulations and procedures) intervene to obtain goods and services from ecosystems. Actions and interventions include the removal or planting of vegetation, harvest of animals, irrigation of landscapes, and construction of systems to control floods. These interventions directly and indirectly modify ecosystem structure and function.

1.2

Expanding the System: Multiple Scales

In the first chapter (Defining the System), you drew a line on the map around an SES or resource system for study. In doing so, you determined the spatial extent of the system under consideration. When we study natural-resource systems, one way to organize the effort is by *spatial scale*. If we want to understand what is happening to a drought-stressed forest, for instance, we could look at a single tree, a patch of trees of similar age, a stand of trees in the same watershed, or a large forest that could span multiple regions. Considering social processes, we may examine different levels of *social organization* instead of studying spatial scale. One could look at communities of different sizes, for instance, from households to neighborhoods, to cities, states and nations. Similarly, in economic systems we can study individual firms, entire sectors, or global economies. The scale or scales at which we focus our investigation will determine, to some degree, what we are able to learn about the problem at hand.

Each of these spatial scales or levels of social organization can also be related to a particular *temporal scale*, measured roughly by the average lifetime of the entity in question. Individual forest trees last a few decades. A stand of trees can last several decades; even though individual trees within the stand have died, the stand itself persists. A large forest can last for centuries, even if patches die off or burn down. [Please refer to Fundamentals for depictions of systems over scales of space and time.]

Similarly, any given household lasts for the lifetime of those in the household; a city can last for centuries.

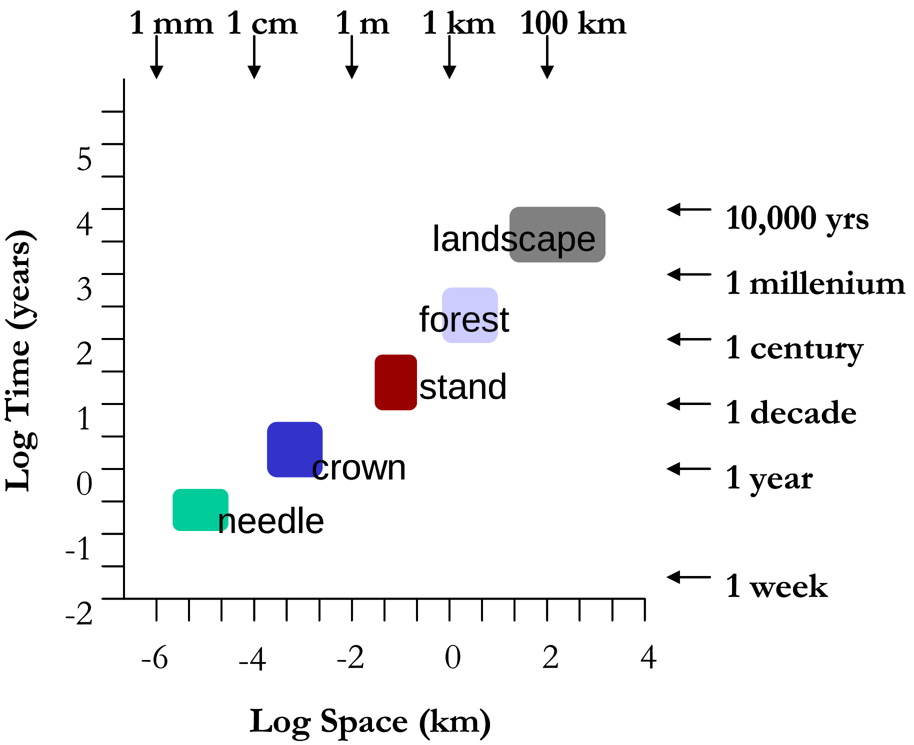
For ecological systems such as forests, lakes, or prairies, we frequently think of a clear relationship between spatial scale and temporal scale, with small things (individual trees) having short lifetimes and larger things (whole forests) having longer lifetimes. Things may not be as clear-cut in social systems—while cities can last for centuries, the nations that claim those cities can come and go. Larger ‘things’ may actually have shorter lifetimes in social systems.

We can represent this on a graph by putting spatial scale on one axis (or level of social organization for social systems) and time on another. For ecological systems, small things have short lifetimes, and so we put a ‘blob’ in the lower left of the graph. (It is a ‘blob’ and not a point because trees can vary in size, and there can also be variation in their age when they die.

So we try to span the relevant sizes and lifetimes with the blob.) Larger things have longer lifetimes, and so the blobs go up and to the right. Social systems may follow the same pattern, or deviate from it.

Examining more than one scale

This graph, however, represents another important point. Not ALL spatial and temporal scales are important in understanding what is going on in the world. If we wanted to understand urban traffic patterns, for instance, we might want to look at travel decisions individual households are making. We may also want to look at what is happening at the neighborhood level—the collection of households within the same school district, for instance. We may look at all the neighborhoods that border a particular highway. But we wouldn't look at single households, and then all combinations of two households, three households, four households, sixty-three households, ninety-one households, and so on. We pick those collections of houses that make some intuitive sense to us.



In ecological systems, small things change quickly and large things change slowly. The same may not be true in social systems.

Complex social-ecological systems operate across a range of scales. If we're interested in something happening at a particular geographic scale—our city, for instance, we usually need to understand something about what is happening at smaller scales (households and neighborhoods, as an example) and larger scales (the state and national level, for instance). Similarly, we may wish to study the health of a particular tree; to do so we might wish to know what is happening to its smaller-scale component parts (leaves and roots) but also to higher-scale components such as the neighboring trees (a stand) or the entire forest. Tackling too many more scales may make the analysis hopelessly complex; tackling too few will eliminate critical details and processes.

The management and sustainability of systems depends on how these different scales interact with each other—what is sometimes called *cross-scale interactions*. But that is the subject of another chapter (Panarchy). Below, you are only going to identify the scales above and below your focal scale.

To understand system dynamics, at least 3-5 variables that operate at different scales are needed.

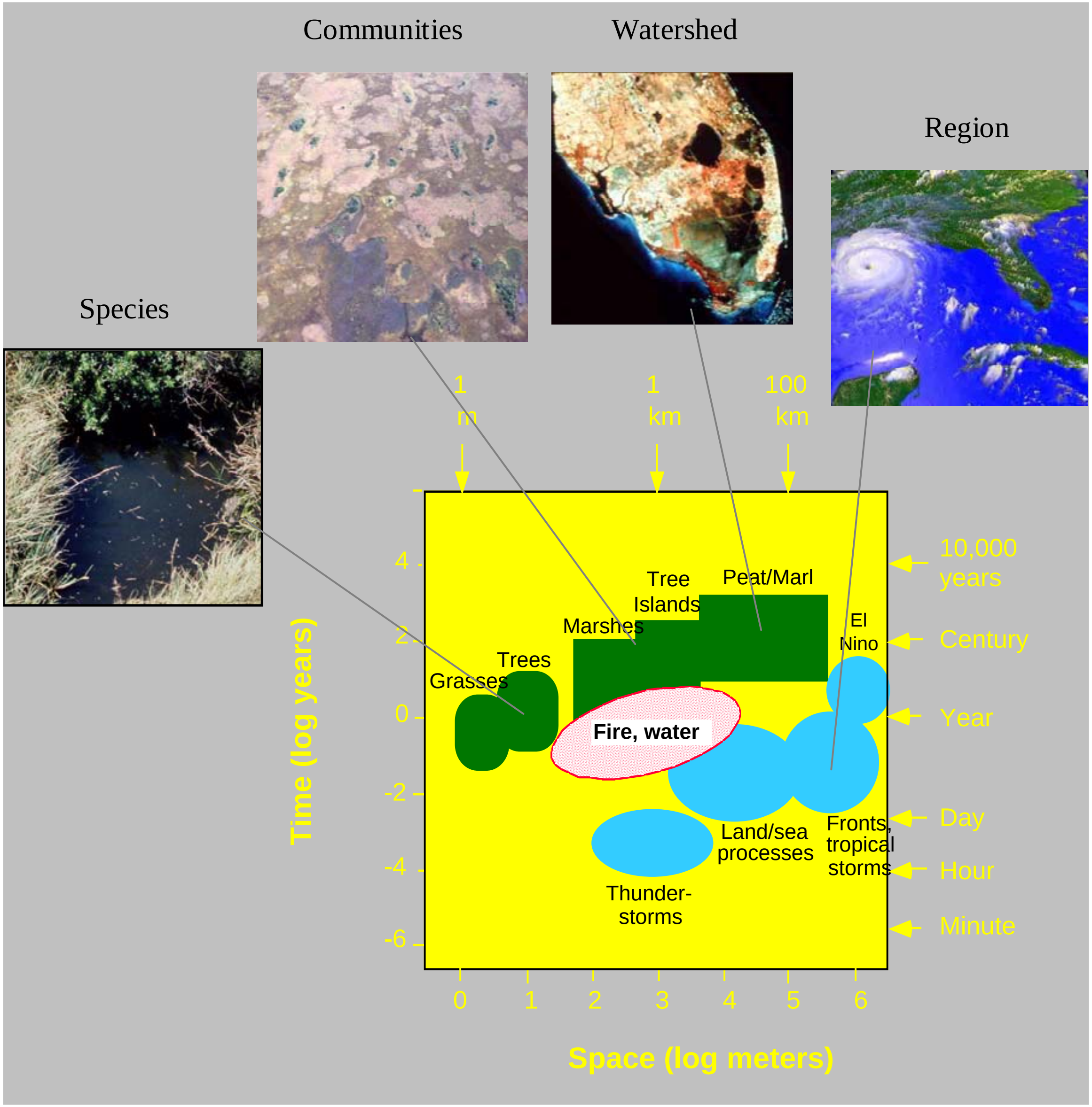
Fundamentals: A Focus on Scales

Scale has two meanings, each relating to measurement of objects. One defines a unit of measurement. A meter, foot and degrees Celsius are different scales, and measures of objects are made using multiples or fractions of these units. For example, it is 18 degrees outside, and my dining room table is 30 inches or 76.2 cm wide. The other definition of the word has to do with relationships among measured units and is derived from the Latin word *scalaris* for ladder. A common meaning of scale (such as a map scale) is a ratio of units. For example the scale of a road map is 1:50,000, where 1 centimeter (cm) on the map equals 50,000 cm on the ground.

A related term is a dimension, which is any measurable entity. Length and width are measures of spatial dimensions. Time is another dimension, in units of seconds, minutes, days, years.

In the types of systems of our concern, two more scale concepts are useful; grain and extent. A grain is defined as the unit of the smallest resolution of measure for a given system dimension. The resolution of a computer screen is defined by the size of picture elements (pixels) that make up the screen, and is a good example of a grain component of scale. The extent of a data set defines the bounds of measurement of a system object. Continuing the computer screen example, the size of the set of pixels (number of rows and columns) is the extent. For two-dimensional spatial data, such as a map, the extent is also called the window of the map. In temporal data, the grain is usually defined as the minimal time unit, such as minute, day, or year, and the extent is the period of record used in analysis. Therefore, scale is defined here by two components: the grain and extent. These concepts are demonstrated in the set of pictures found in Figure 2.

Figure 2: Aerial images of Everglades covering different scale ranges. A) Individual plants and trees are visible within a window spanning 10 m, b) Plant associations (marshes and tree islands) are seen at a window of 300 m, c) landforms and watersheds are seen at a window of 300 km, and d) geologic features, and tropical cyclones are visible at windows of 1000 km.

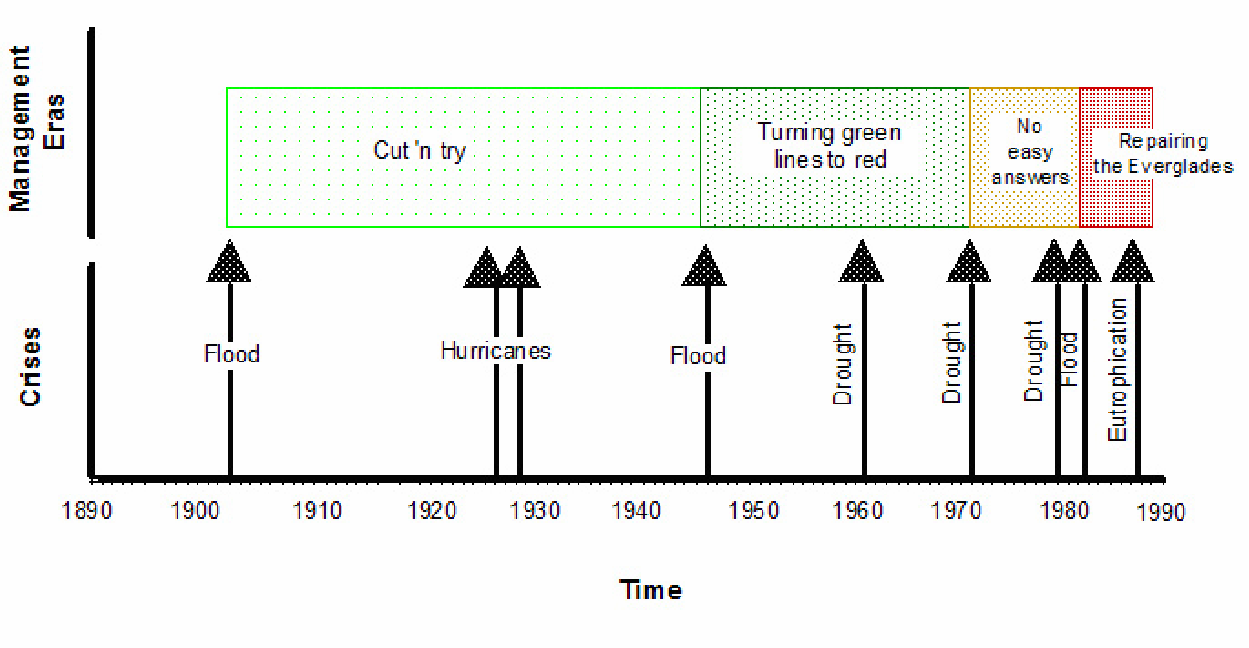

Communities
Watershed
Region
Species
1 m
1 km
100 km
Time (log years)
4
2
0
-2
-4
-6
Tree Islands
Peat/Marl
Marshes
El Nino
Trees
Grasses
Fire, water
Land/sea processes
Fronts, tropical storms
Thunder-storms
10,000 years
Century
Year
Day
Hour
Minute
0
1
2
3
4
5
6
Space (log meters)

1.3

Linking the Past to Present: Historical Timeline

Prior analyses of social ecological systems indicate that developing a historical profile of different regimes is useful for understanding resilience. In the first part of this section, you defined the system in terms of spatial dimensions. This chapter will expand that understanding in the temporal dimension. Historical profiles can reveal the history of human interventions and management actions, how understanding and values of the system have changed and patterns of slow and predictable change interspersed by episodic and rapid change.

Social ecological systems undergo change over time. Those changes can be slow and predictable, or they may be fast and unforeseen. In this assessment you will create a historical profile of the system identified in the first set of assessments. The history should focus on different eras (such as management era or economic era) and why these eras changed. This should not be a detailed reconstruction, but rather a broad overview of different time periods that have a logical grouping. What is important is to determine what is different among these time periods, and what led to these changes in the system. The eras may be characterized by political differences such as a community or local led initiative for a certain period of time that is replaced by a governmental led project. These may be economic changes, such as a shift in markets or resource use. The eras may be characterized by ecological changes such as the loss of species, change in habitats, or collapse of populations. The eras may be characterized by technologic changes, such as the advent of new forms of irrigation.



Everglade Water Management Timeline, late 1800s to late 1900s

1.4

Resilience To What? - Disturbance

Systems often change state as the result of *disturbances.* Indeed, the loss of ecological resilience becomes obvious when a disturbance that had occurred in system many times before all of the sudden generates a shift in state. Disturbances can external to the system—a hurricane, for instance, Disturbances may be a management tool-such as prescribed fire.

What, exactly, is a disturbance? There is no universally agreed upon definition. A general description is that a disturbance is anything that alters the state of the system. This could encompass many phenomenon that are quite regular and predictable—seasonal weather changes, for instance, or new government budgets. Of course, some seasonal weather changes *do* cause a disturbance—an unusually harsh winter, or a shift in the timing of spring snowmelt due to climatic change.

Of course, many human activities could be said to fall into this category as well. Natural-resource managers should be interested in these types of activities, though, and for the purpose of working through these assessments we would categorize them as a disturbance for three reasons: (1) Human activities are often recent relative to the age of the natural-resource system being managed. They therefore still constitute novel change to which the ecological system may not be fully adapted. This can be true even if the human activity is several centuries old. This is particularly true in cases where (2) The nature, magnitude, or impact of the human activity is changing over time. This often happens due to increasing population size, changes in technology, or changes in policy and management strategies. Furthermore (3) Many human activities are designed to provide greater quantities of a desired resource. This is a perfectly reasonable strategy, but often has the effect of moving the system closer to a threshold between states—in other words, making it more likely to change when disturbed. Finally, (4) disturbances may be a useful management tool in moving a system from undesirable to desirable states.

By trying to maximize use or control disturbances, humans can decrease the resilience of managed systems.

This last point suggests that disturbances needn't be considered in a negative way. Some degree of disturbance is actually necessary to maintain the resilience of the system. Eco-

disturbance

systems that have existed in relative isolation, for instance, rarely experiencing the arrival of new species can be extremely susceptible to invasion if new species do appear. Disturbances can help maintain diversity in ecological systems—a pool of species adapted to different conditions. Disturbances in human communities can help forge the policies and alliances that provide the capacity to weather the next disturbance. And human disturbances to natural resource systems have been essential in our development of agriculture, urbanization, technology, and the arts. Disturbances are an inherent part of our social and ecological systems. For this reason, management strategies that try to overly suppress disturbance often backfire. The ecological (or human) system loses its capacity to respond to disturbance, and small disturbances can then have large consequence for the system (since management can never suppress all disturbance).

Disturbances can be characterized in many ways—by their frequency, duration, severity, or predictability, to name just a few. For our purposes, we will consider a few categories.

The first would be 'pulse' versus 'press' disturbances. 'Pulse' disturbances are events that occur and then cease before recurring (if indeed they do recur). 'Press' disturbances would be unremitting. While most disturbances are likely to be pulse disturbances—plowing, hurricanes, disease outbreaks—some may be press (for instance, a grazing land that is stocked year round).

For pulse disturbances, it can be useful to know if they are regular (relatively predictable in their occurrence) or sporadic (coming somewhat unpredictably). Many of the most important disturbances, and those that can be most difficult to manage because of the uncertainty associated with them, are sporadic. Droughts or floods, for instance, occur at multiple frequencies, not just one. It is also useful to know whether the system has had time to fully recover between events or only partially recover, or what the probability of only partial recovery would be.

Some disturbance is necessary for maintaining or enhancing resilience.

For both pulse and press disturbances, the magnitude of the impact should also be characterized. For some disturbances, the impact may always be large, or always small. For others—for instance, fire—the magnitude may vary, depending on the severity of the event. One should also assess whether the nature of the disturbance is changing over time, and in what way. Is it becoming more frequent, more severe, less damaging? Finally, it is useful to know whether the nature or magnitude of the disturbance can be influenced by local practice or policies, or whether it is beyond the control of stakeholders.

Taken together, all of the disturbances in a natural resource system can be taken as a 'disturbance suite'.[1] Multiple disturbances can be particularly

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[1] In the ecological literature, this is often called a disturbance regime, but this use of the word regime is distinct from that which appears in other chapters. To avoid confusion, we use disturbance suite here.

critical. If one disturbance has already moved the system towards a threshold, and another occurs before the system has time to recover, the crossing of a threshold is more likely. Recall that overly suppressing disturbances can reduce the resilience of a system, and many disturbances cannot be altered through management action. Therefore, if disturbances become increasingly large or frequent, a goal of management should be to keep the system further from a threshold than would be necessary if disturbances were small or infrequent.

In the activities that follow, you'll be characterizing the disturbances in your own system, and some of the impacts of those disturbances. You'll learn more about thresholds in the next few chapters, and will return to disturbances thereafter to assess which threshold(s) they may be pushing the systems towards.

Part 2:

Assessing Alternate States and Thresholds

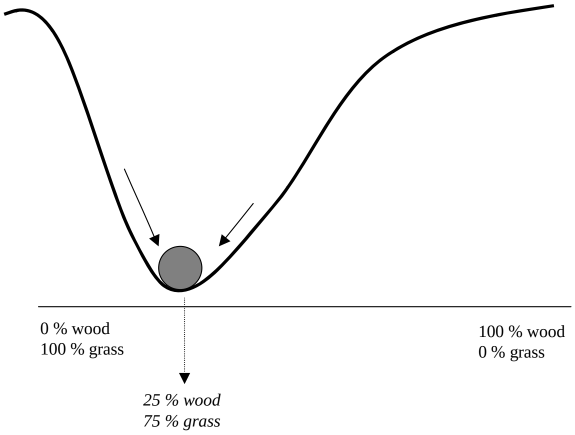
The next 2 steps are structured to assess possible alternate states of your system, and the processes or disturbances that could cause the system to ‘flip’ from one state to another.

2.1
Alternative States

Many ecosystems show consistent traits over long periods of time. Grassy savannas can stay grassy savannas for decades; large-scale ocean currents such as the Gulf Stream can show substantial persistence; once algae chokes a lake it can be difficult to remove.

The existence of these long-term and persistent characteristics led scientists to recognize a phenomenon known as ‘stable states’. ‘Stable’ in this sense doesn’t imply complete lack of change. There can be some degree of variation while the overall characteristics of the system remain largely the same. Grasses may grow well in some years and be less abundant in others but the overall landscape still looks and functions like a grassy savanna. The Gulf Stream may drift to the east in some years, but it is still flowing, and still recognizable as the Gulf Stream. Water temperature and nutrient concentrations in the lake may fluctuate, but the lake may still be clogged with algae.

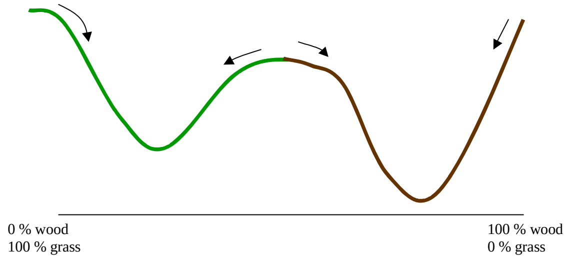
Consider the savanna example in more detail. Savanna ecosystems are comprised of grasses with a few trees or shrubs. For some savannas, there may be only one possible stable state—one combination of grassy and woody plants that tends to persist over time. (Scientists frequently determine the number of stable states, and their proportions of woody and grassy plants, mathematically, but we won’t go into the details of that here.) One way of representing system states is to use a ‘ball and basin’ diagram. The stable point in the system is represented as the bottom of the basin. The current state of the system is represented by the position of a ball. The ball will tend to roll towards the bottom of the basin—towards the stable point—in this case taken as 25% woody plants and 75% grassy plants. If the system is perturbed away from that stable point—if some woody plants are harvested for fuel, for instance—the system (ball) will temporarily move away from that stable point, but will eventually drift (roll) back.



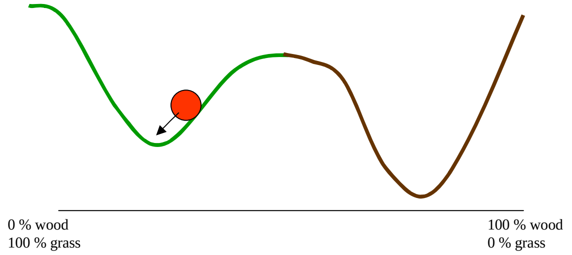
Multiple Stable States

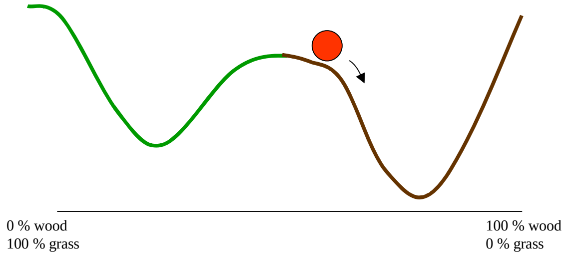
Frequently, though, there is more than one stable point. Consider a savanna system with two stable points—lots of grass and little wood, and lots of wood and little grass. Each of these stable points has an associated 'basin of attraction'—the system will tend towards the bottom of whatever valley it finds itself in.

What if we start in the basin of lots of grass and little wood and use it as a rangeland—putting cattle in that eat some of the grass? If we only have a few cattle—only a little grass is eaten—we are still in the basin with lots of grass but may have shifted slightly from the most stable point (bottom) of the basin. If the cattle were removed, the savanna would tend to return to its grassy state.



But what if a lot of grass is eaten? Then the system may move over the 'hilltop'—or threshold—and into a different basin—the basin where there is little grass but a lot of wood. Even if the cattle are removed, the system will tend to stay in that basin, moving towards the stable state of low grass and high wood.





The width and depth of the basins tell us something about how hard it can be to move from one basin to another. If the 'woody basin' is very steep, for instance, then it can be very hard to move the ball around, or change the amount of wood in the system. If a basin is very wide then the amount of grass (or wood) can be changed by quite a bit before sliding into a different basin.

Dynamic nature of systems

Basins that are wide and deep are resilient—the system once in those basins can withstand a lot of changes or disturbances without moving to a new basin. Basins that are narrow and shallow are less resilient—slight perturbations can send the system off into fundamentally new states. Note that there needn't be any correspondence between resilient states and desirable states—states we would rather avoid might be quite resilient (steep and wide basins) and states we are trying to achieve might be quite fragile.

There are four important additional points to make. The first is that the positions of the valley bottoms and the thresholds or hilltops between them are not fixed—these too can change. So, for instance, if there is a prolonged drought, the threshold between the grassy savanna and the woody savanna may itself shift. We may have thought we were stocking the cattle at a point where we were still in the basin for a grassy savanna, but the shift in the threshold could suddenly bring us into the woody savanna—a previously 'safe' stocking level becomes unsafe if we wanted to avoid losing our grassy savanna. Note, then, that management strategies that bring us close to thresholds may be unsafe—a point we return to in later chapters.

Thresholds between states (basins) can themselves shift, such that previously safe management practices become unsafe if one wishes to avoid a change in state.

The second is that some basins are so deep, or so wide, that once entered they can be extremely difficult to leave. In fact, some changes may be effectively irreversible from the perspective of the people alive today. One of the challenges of managing for resilience is to make the desirable basins more resilient and the undesirable basins less resilient, whenever possible. Another challenge is to avoid sliding into the undesirable basins all together, particularly when they are deep or wide. Again, we return to that throughout this working book.

Some states are difficult if not impossible to leave once entered. These states would be highly resilient, though not necessarily desirable

The third is that the basin and ball picture presented is obviously highly simplified. We've already learned the position of thresholds can change with changes in rainfall. They can also change depending on the timing of grazing—when cattle are moved onto and off of the rangeland. They could change if an invasive species appeared in the system, or technologies for combating undesirable species were improved. There are many things that could alter the picture—and many of them have to do with the ways humans are managing the system.

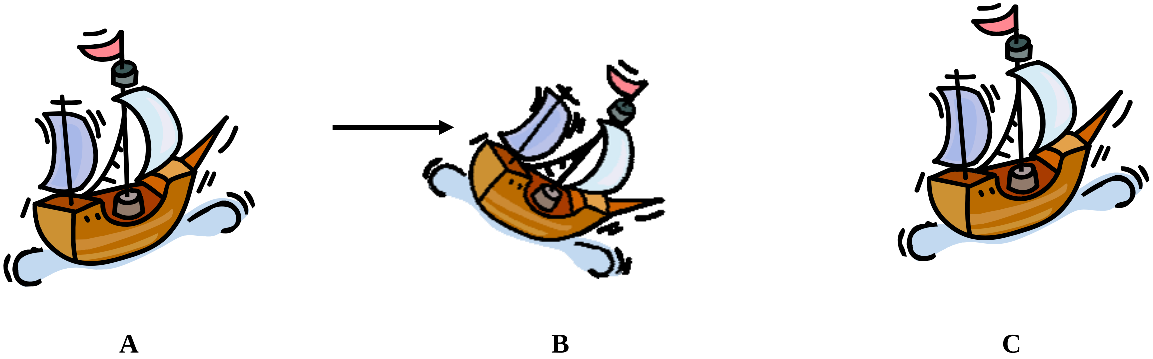
This corresponds to the main message of our previous chapters—that we need to think of coupled social-ecological systems. For purposes of illustration, we've mainly talked about an ecological system here. But there would be corresponding social basins as well. If a community is highly dependent on cattle, then the 'grassy' basin also corresponds to an economic basin of prosperity. Disturbances that altered that prosperity might lead to different stocking strategies, which could, in turn, alter the threshold between grassy and woody savannas. In thinking about alternative states, we must think about both the ecological and social components.

The final point—perhaps a bit esoteric—is that there is not always a stable point at the bottom of the basin. A basin can instead be anchored by something called an ‘attractor’. If there is an attractor at the valley bottom rather than a stable point, the ball may tend to roll around in the basin a bit more. But one may expect the ball to roll around a bit anyway—because the weather may be slightly different from year to year, or because people make different choices about the number of cattle to stock. For our purposes, the difference between an attractor and a stable point is probably not important. But it is probably more accurate to talk about alternative states rather than alternative stable states—with the understanding that a particular state can still show a lot of variation from week to week, or year to year, or decade to decade, and still be in the same basin of attraction.

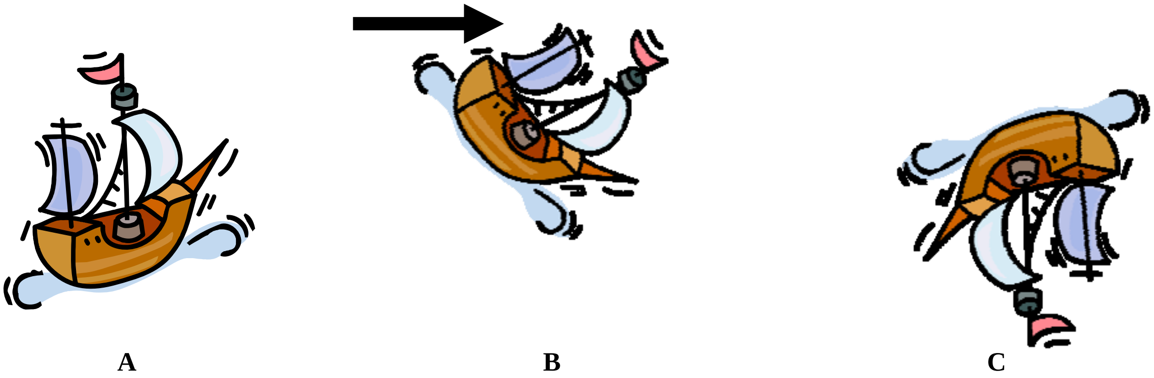
In the assessment that follows, you will be trying to define some of the alternative states for your system, and the processes (such as grazing in the examples above) that might move your system from one state to another. You’ll draw both on past experience and on future projections to think about what these alternative states—the basins—might be. Don’t worry for now about the exact position of the hilltops between them—that’s the subject for another chapter. Rather we’re just trying to identify the general basins—grassy and woody savannas, for instance. But remember to think about social and economic states as well as ecological ones as you work through the following assessment.

Fundamentals. Engineering versus Ecological Resilience.

A general meaning of resilience is the ability of a system to cope with stress or disturbance. Although many different interpretations of the meaning can be found in different fields of study, we focus on two meanings that were derived from the study of ecological systems; engineering resilience and ecological resilience. Engineering resilience refers to how quickly a system can recover from a disturbance and is related to the stability of a system. Ecological resilience is defined as the capacity of a system to absorb disturbances and retain similar system characteristics. A distinction between these two terms involves whether systems enter into alternative configurations, also called regimes or states. Engineering resilience assumes one system configuration, and that disturbances create a temporary change before returning to that configuration. Ecosystems, and other complicated systems, however do not have just one configuration or regime. Ecological resilience, therefore, refers to the amount of disturbance needed to change from one configuration to another. A simple cartoon can help illustrate the differences.



Engineering Resilience. We use a basic analogy of a sailboat at sea (the system) to illustrate the speed of return to previous regime definition. A) Sailboats are designed to stay upright and counteract the forces of wind. B) A gust of wind (the disturbance) causes the boat to list. C) As the wind dies down, the boat returns to its previous state.



Ecological Resilience. Using the same analogy of a sailboat as the system this figure illustrates how the amount of disturbance (in this case the wind) can shift the system from one regime to another. A) Sailboats are designed to stay upright and counteract the forces of wind. B) A stronger gust of wind (larger disturbance) causes the boat to list. C) Once it passes a certain angle (righting moment = threshold), the boat will capsize. The capsized position can be thought of as an alternative regime, certainly less desirable than the upright one!

Fundamentals. Social Regime Shifts.

The social components of a socio ecologic system can undergo regime shifts as well. As with the ecological regime shift, this change fundamentally alters the way the system looks (its structure) and functions (processes), thus creating a new regime.

New regimes can involve the creation of new management institutions. Examples include formal institutions such as governmental agencies to manage forest or water resources., or non-governmental agencies to conserve specific resources. Regime shifts can occur with the emergence of informal institutions, such as new rule sets for harvesting fish among traditional fishers. These institutions may address issues at multiple scales, from very local to international scales. The table below shows how environmental events in the history of the Everglades led to the creation of new management institutions.

One way in which new social regimes emerge is following ecological crises. Indeed many of the ecological regime shifts in the previous section can be described as ecological crises. In the wetland nutrient example above, new rules were developed to avoid nutrient pollution to from spreading. The rules involved how water is managed, and shifts in land use changes, as land was purchased to create wetlands to remove the nutrients. Regime shifts can also arise from shifts in social values or views. For example, the creation of a national park or reserve may be a result of a conservation values.

Table Box 6. Example of social regime shifts (the appearance of new management agencies or groups) that arose from environmental events in the Everglades during the 20th century.

ENVIRONMENTAL EVENT	SOCIAL REGIME SHIFT
Flood 1903	Drainage District
Hurricanes 1920's	Corps of Engineers
Flood 1947	Flood Control District
Drought 1971	Water Management District
Crisis 1983	Everglades Coalition
Restoration 1994	Fed/State/Local Meshing Groups

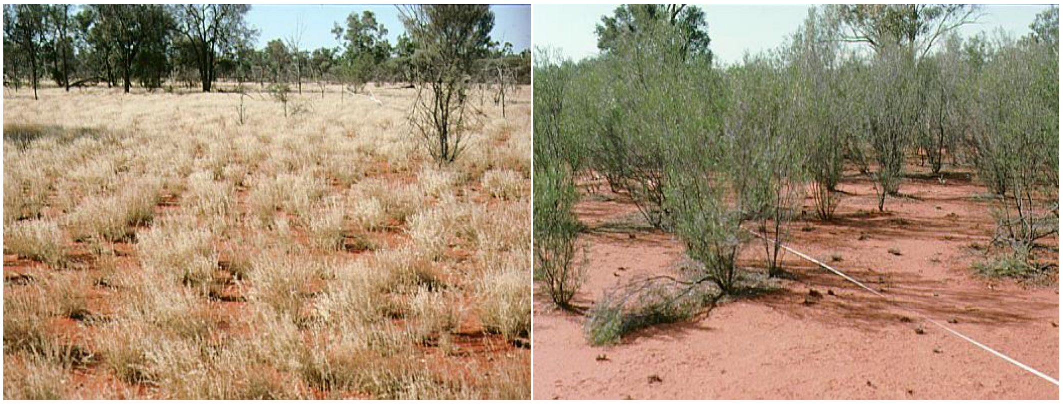
Fundamentals. Ecological Regime Shifts

An ecological regime shift occurs when characteristic or defining features of an ecosystem change. The change fundamentally alters the way the system looks (its structure) and functions (processes), thus creating a new regime. The ecological components of coupled systems undergo dramatic transformations, or regime shifts, as a result of human interventions.

All over the planet, humans directly and indirectly modify ecosystems to secure a supply of goods and services. In poorly-managed systems this can result in ecological regime shifts, for example:

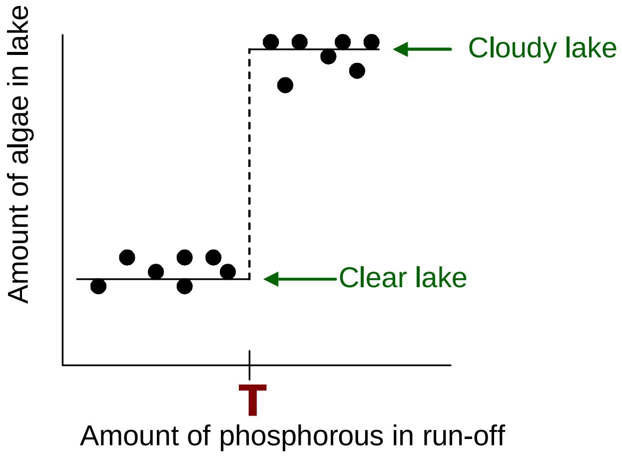
- Forests change and habitat is lost as humans remove trees for fuel, timber, and pulp.
- Intensive agriculture removes native biodiversity, and replaces it with a monoculture of crops that are maintained by large subsidies of water, nutrients and fossil fuel.
- Lakes, rivers and estuaries become eutrophic from non-point pollutants
- Overgrazed rangelands become woodlands.
- Excessive water use leads to soil salinization.
- Over-fished coral reefs become covered with algae.

Each of the examples above describes an ecological regime shift, whereby the structure and linkages that characterize one regime are replaced by others. Some of the changes are brought about by direct manipulation, such as agriculture and forestry practices. Others, such as water pollution and algae-covered reefs are the indirect result of other activities. Ecosystem regime shifts can be slow and gradual or fast and sudden. In many cases, the alternative regimes are less productive, less desirable, and generate consequences for livelihoods, security and conflict.

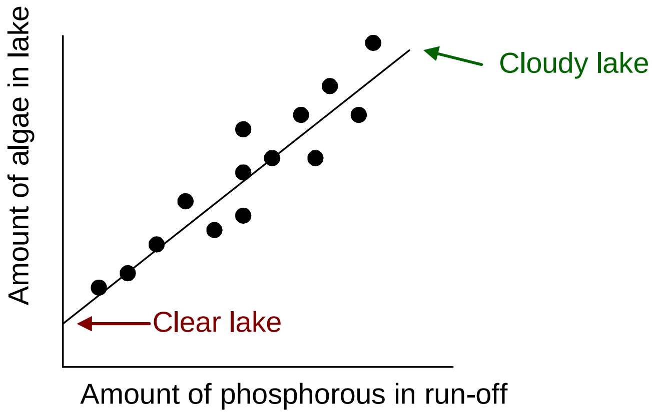


Photographs of alternative regimes in terrestrial systems. The grass dominated regime is used for grazing and is maintained by frequent fires. Overgrazing and removal of drought tolerant species can cause a transition from a grass dominated landscape to one covered in shrubs (Mulga). The shrub state has insufficient fuel to carry a fire . It can take decades for the shrubs to thin out through competition and self-thinning, to allow for establishment of sufficient grass cover and fire regime to maintain the grass state. (Australia)

2.2
Thresholds



As we saw in the previous chapter, a fairly common way of depicting alternative states is with a ball and basin metaphor. There are other approaches, however, to depicting alternative states.



Imagine that you own a cottage on a lake. You notice that in some years the water is cloudy with algae, in other years clear. You being to realize that algae levels in the lake are related to the amount of phosphorous in the water reaching the lake. More phosphorous means more algae. You begin measuring the phosphorous in run-off, measuring the cloudiness in the lake, and a pattern emerges. In years when phosphorous in run-off is high, the nutrient inputs stimulate algae growth and the lake is cloudy. When it’s low, there aren’t enough nutrients for algal growth and the lake is clear.

In this case, there are not alternative states of ‘cloudy’ and ‘clear’. Instead, the lake can have any state between completely clear and completely cloudy, depending on the amount of P (phosphorous) in the water.

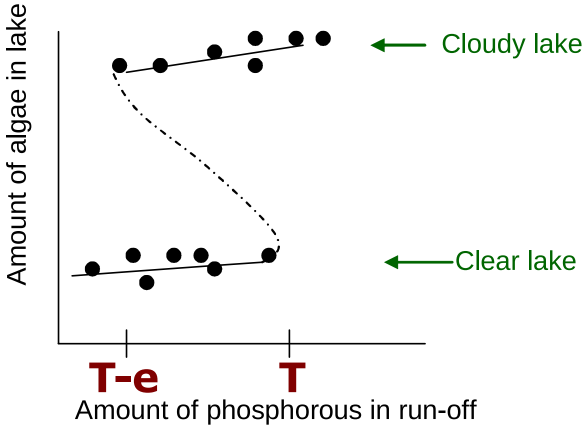
Now imagine that you have come to reside next to another lake. You continue your hobby of measuring P in run-off and measuring the cloudiness of the lake water. But this time, a very different picture emerges. Now, for a variety of P inputs to the lake, the water remains relatively clear. But when a certain level T (for ***threshold***) is reached, the water suddenly becomes cloudy.

For any given level of P in the run-off, only one state of the lake is possible (clear or cloudy). When P in run-off exceeds the threshold T, the lake is cloudy. If, in the next year, P in run-off falls below T, the lake becomes clear. Here there is a threshold effect—a point past which the lake suddenly flips from clear to cloudy. This type of threshold is relatively easy to manage, as restoring P in run-off to a level below T restores a clear lake. The 'flip' to a new state is reversible.

You wander off to a third lake to continue your studies. For a few years in a row, P in run-off is low, and the lake is clear. Then, one year, P in run-off is high (exceeds the threshold T), and the lake becomes cloudy. The next year P inputs are again reduced below the threshold T, and you expect a clear lake to re-emerge. But the lake remains cloudy. What has happened?

As long as the lake is clear and P input values fall below T, the lake will remain clear. But if input values exceed T for even one year, we 'flip' to the cloudy water state. Nor will reducing P input values just below T restore the clear lake. Instead we must reduce them to a level T-e (e for effort) to restore the clear lake system.

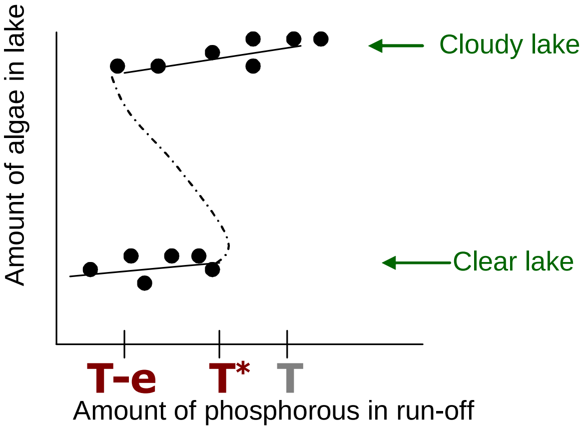
So, for a range of values of P inputs between T – e and T we have true alternative states—either the clear lake or a cloudy lake is possible. Whether the lake is in one state or the other depends on what has happened in previous years. Once the lake becomes cloudy, P inputs must drop to T-e for it to become clear again. Once it is clear, P inputs must rise to T for it to become cloudy again.



This type of 'folded curve' shown in the figure above is known as a 'hysteresis' curve (from the Greek husteros, meaning 'late'). The degree of the fold can tell one something about the reversibility or irreversibility of a change in state. If the fold is large (i.e., the distance between T and T – e is large), the change in state is somewhat irreversible—it will take a large effort to restore the clear lake. If T-e falls in the *negative* region of the x-axis the change in state is effectively irreversible—since phosphorous levels in run-off cannot be reduced to negative levels, there is no reasonable way to restore the clear-lake system. If, in contrast, we just have a step function (as in the second lake we studied), the change in state is very reversible—one need just reduce P input levels below T to restore the clear lake system. Managing thresholds in part requires understanding the degree of hysteresis in critical relationships, and whether or not changes in state are likely to be reversible.

With supreme effort, you and the residents around the lake manage to reduce P inputs below the T-e level, and to keep them low for many years. One year, however, the P inputs rise slightly—to a level T^*. This is still well below T, however, so you expect the lake to remain clear. Instead, it flips to a cloudy state. Why?

One critical insight of resilience theory is that the *thresholds themselves can change* as time passes. The shift in thresholds can lead to a loss of resilience – when disturbances that could previously be tolerated (in this case, P inputs at the level T^*), lead to a change in state.



Numerous case studies suggest that rigid management—controlling strictly for a given yield in an extractive system, for instance—tends to move the threshold in so that the system is less resilient (more vulnerable to a regime change). Other forms of management, such as adaptive management, can maintain the positions of thresholds or even move them out so that the system is more resilient. We return to that in more detail in later chapters.

But why does the threshold move? In analyzing many different lakes, scientists have discovered that there are two main inputs of phosphorous to the lake water. One is from run-off—phosphorous bound up in eroded soil or leached from fertilizer in farm fields can find its way into the lake during rain and drainage events. The other is from the lake sediments themselves. The amount of phosphorous released from the sediments depends on the oxygen status of the lake, and on the concentration of phosphorous in the sediment to begin with. When oxygen levels are low, and sediment concentrations are high, phosphorous is released from sediments.

Changes in slow variables lead to changes in the position of thresholds over time, such that systems become less resilient.

But what causes low oxygen levels? It turns out that the decomposition of dead algae consumes oxygen. So, algal blooms occur when additional phosphorous appears in the system—perhaps from run-off. As the algae die, they are decomposed, and oxygen is used up. That lack of oxygen can cause the release of additional phosphorous, driving additional algal growth.

If there isn't that much phosphorous in the sediment, not much will be released, and algal growth can be controlled as long as P levels in run-off stay below T. But if there is a lot of phosphorous in sediments, that P starts to be released. Now when P in run-off exceeds T^*, there will be runaway algal growth and the lack will become turbid (cloudy).

Some of the phosphorous in run-off eventually finds its way into the lake sediment. Thus, the longer a lake has been experiencing the disturbance of elevated phosphorous in run-off, the more phosphorous is found bound up in sediments. The more phosphorous there is in sediments, the more likely an initial algal growth is likely to 'run away'—fueling phosphorous release and more algal growth. In other words, the basin for the clear-water state shrinks. Changes in algal growth and water quality that could be tolerated when phosphorous levels in lake sediments were low can no longer be tolerated when phosphorous levels in lake sediments are high.

Management that stabilizes or optimizes systems tends to move thresholds and make systems less resilient.

The key point here is that it is a change in a slow variable that is driving the change in the position of the threshold. Phosphorous in the lake water itself may change rapidly, but phosphorous levels in the lake sediment change only slowly. If we overlook these changes in slow variables—if we assume our lake today can always withstand perturbations of the size it has withstood in the past—we may be unpleasantly surprised.

Of course phosphorous in lake sediments is only one example of a slow variable operating in a social-ecological system. Nutrients in soils or sediments can change slowly, and so they are often good candidates for slow variables that may control threshold dynamics. (Note that not all nutrients are created equal. In our lake example, algal growth was limited by phosphorous. So it was the change in phosphorous in the sediment—rather than, say, manganese or nitrogen—that was important in shifting the threshold, even though nitrogen and manganese would also be slowly-changing variables.) The population size or biomass of long-lived species, including humans, may also represent important slow variables. In social systems, culture can be a slow variable, as can rules and norms. Economically, changes in the dominance of a certain currency, or in the structure of markets, may be slow.

Key in identifying those variables that will prove to be critical in shifting thresholds is to first think of those attributes that are changing slowly relative to other dynamics of the social-ecological system. Identifying which of these will prove to be critical in shifting thresholds can be a bit more challenging, requiring in many instances in-depth natural- or social-science analysis and a bit of long-term experience and intuition about the workings of the system. One must also recognize the social-economic slow variables that parallel ecological variables, and vice versa. Phosphorous inputs to lakes, for instance, are directly related to fertilizer markets, farming practices, and regulatory frameworks that may themselves be slowly changing. A key challenge for management lies in identifying critical slow variables and then monitoring them for change. We'll begin that process in the assessments to follow, but sufficient understanding and management of slow variables will likely require further research and collaboration among natural scientists, social scientists, other stakeholders, and managers.

Part 3:
Assessing and Managing Cycles of Change

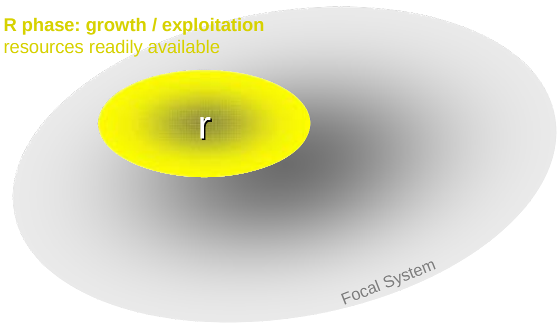
In the next 2 steps, you will be assessing cycles of change in your focal system, determining how influences from finer and coarser scales influence resilience, and formulating a plan for managing cycles of change and cross-scale interactions.

3.1
Cycles of Change: The Adaptive Cycle

In a previous chapter, you defined a social-ecological, or *focal*, system. Most systems are not static—staying the same—but dynamic, in that they change over time and over space. This chapter is about those changes over time at different scales. System changes can be rapid, or slow. They can also be relatively predictable, or highly uncertain.

At the core of resilience theory is the notion of an adaptive cycle. The adaptive cycle describes a general way in which many systems may change—particularly the natural-resource systems we're interested in, such as fisheries, forests, grazing systems, along with the people who use them. The central idea is that these changes, while not quite completely predictable, are far from completely uncertain. Instead, we can recognize four distinct phases. The way in which systems move from one phase to the next is termed the adaptive cycle. We see this adaptive cycle playing out across scales—your focal system may experience these four phases, as may systems at other scales.

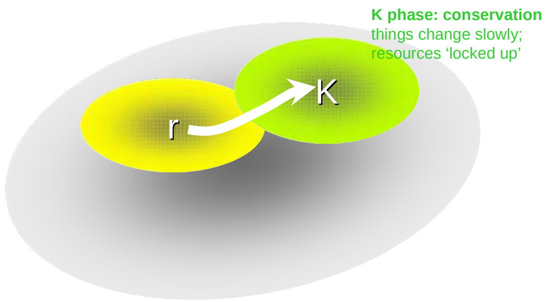
Let's start with the growth, or r phase. The term (r) is taken from ecology, but it applies to other types of non-ecological systems as well. When new ecological spaces open up—due, for instance, to forest fires, or retreating glaciers, or many other things—resources needed for other species to grow are made available. There's more light reaching the soil surface when large trees are toppled, or burned to the ground, for example. The nutrients in those trees are also released. Other agents of change or disturbance—such as hurricanes or disease—can open up new space for colonization and release nutrients and other resources for utilization.



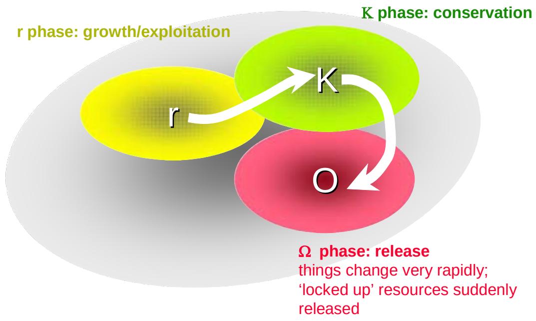
Certain species of plants and animals are well adapted to taking advantage of these newly created habitats. Some fast-growing species—what ecologists call, coincidentally, r-selected species—are best able to take advantage of these conditions. These species tend to be fast-growing, short-lived, and highly reproductive. They can rapidly colonize a site and begin to use the existing resources. You will have witnessed this yourself if you have ever farmed or gardened. When the soil is plowed, and the space and nutrients are made available, fast-growing weeds quickly invade your plots.

But we don't just see this phenomenon in ecological systems. Resources can suddenly become available in economic or social systems, as well. Consider, for instance, the possibility of a new business opportunity related to an innovative technology (such as the microchip). In the 1970's many small, 'flexible' companies formed and tried to rapidly acquire a significant share of the new personal computer market. This r-phase is sometimes called the growth or exploitation phase, characterized by widely available resources, and fast-growing, small entities capable of using those resources and growing rapidly .

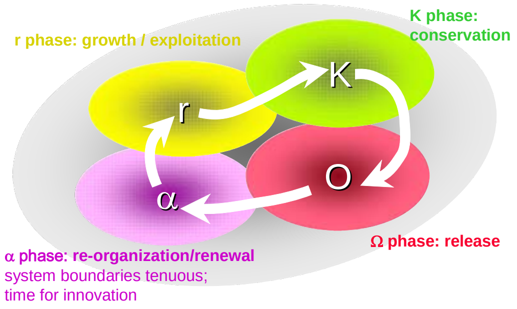
The r phase is transitory, and as the system matures, it is replaced by the K phase. Eventually slower growing, long-lived species or entities enter the system. Resources become less widely available as they become "locked up" in these slow-growing entities. (The fast-growing plant species have died or been replaced by more effective competitors; the small, flexible companies have disappeared, moved on to new opportunities or evolved into larger, more dominant firms.). The K phase is sometimes called the conservation phase, because energy acquired goes into maintaining or conserving existing structure, rather than building new structure. In this phase, a few dominant species or companies or countries—depending on the domain or scale being considered—have acquired many of the resources and are controlling the way they can be used. Systems often move very slowly from the r-phase, where there are many different species or companies, toward the K-phase, where only a few species or companies and their way of using resources have become dominant.



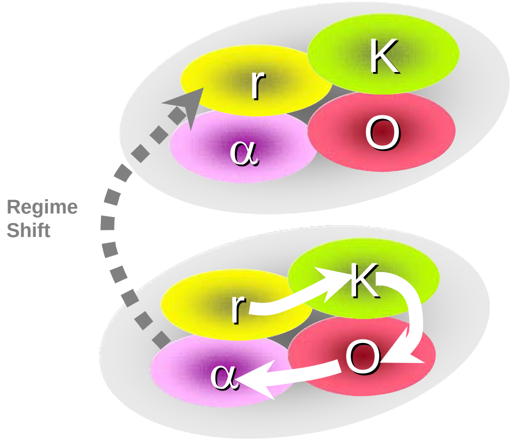
One central tenant of resilience theory is that the longer the system stays in the K phase, the more vulnerable it is to disturbance. The system becomes vulnerable because of the accumulated structure and numerous connections among components in the system. For example, in conifer forests older, more densely packed stands of trees are more susceptible to fire or insect outbreaks. In general, as a few species or companies come to dominate the system, the system becomes less and less flexible and more entrenched in particular ways of using resources. While this has the advantage, in many cases, of making the system more efficient, it can also increase the vulnerability of the system. The increase in vulnerability eventually leads to the next phase of the cycle.



Often systems rapidly pass into a phase called omega. This is also referred to as the release (or creative destruction) phase because structure, relationships, capital or complexity accumulated during the r and K phases is released (often in a dramatic or abrupt fashion). Plants may die (or be killed), releasing the nutrients held in the leaves and stems back into the soil, or a company may go bankrupt, releasing workers and decommissioning factories or offices. This phase may be disturbance driven, such as the pest or fire example in the previous paragraph. They can also be planned or programmed disturbances such as prescribed fire management, or the declaration of bankruptcy by a business. Release frequently (but not always) happens very quickly and the system rapidly moves into the next phase.

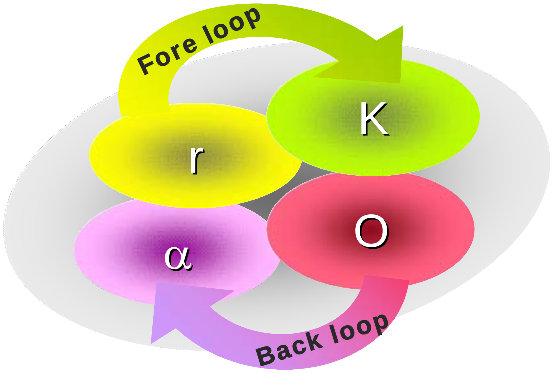


The fourth, or the alpha phase, is a period of reorganization, in which some of the entities previously released begin to be re-structured but not necessarily as they were before. This phase can mark the beginning of another trip through an adaptive cycle similar to the previous one, or the switch to a new adaptive cycle. In this reorganization phase, system boundaries are tenuous. Many new entities may enter the system, and innovation becomes more probable. It can be difficult to see what might emerge from this phase, because not all of the species, or businesses, or innovations will be successful. Eventually a few will establish themselves, however, and carry the system into the next r phase. But this time, the companies or species that dominate the r-phase might be different.

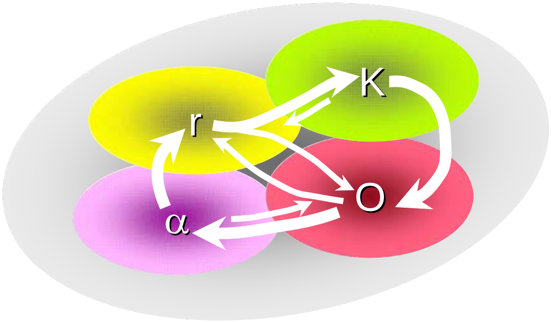


This last point is a critical one. As systems move through adaptive cycles, subsequent cycles may look similar to previous ones, or they may look drastically different. It is in the alpha phase that new possibilities emerge, and in the r-phase that those possibilities begin to ‘sort themselves out’, as it were, with certain players or strategies coming to dominate. Those winning strategies and players can be very familiar—repeating earlier adaptive cycles—or very unfamiliar, representing something completely new. Again, it is at the reorganization phase that many systems can change regimes, and hence begin a new adaptive cycle.

In an earlier chapter, we learned about a different way of thinking about the dynamics of systems—namely the ‘ball and basin’ approach. In a very loose way, one can relate the adaptive cycle to the ball and basin concept. The dynamics implied by the adaptive cycle can be taken as akin to a ball rolling around in the basin. A new adaptive cycle may appear if the ball (representing the current state of the system relative to the basin) were to reach a threshold and roll into a new basin. A repeat of an adaptive cycle might occur if the ball were to reach a threshold but roll back into the old basin. This picture is a bit overly simplistic, and we’ll learn more about what might determine whether adaptive cycles are repeated or new in subsequent chapters, but the two analogies of adaptive cycles and balls and basins can both be useful in thinking about the dynamics of complex systems.



A common trajectory through the adaptive cycle is to go from r to K to omega to alpha. The r to K transition is sometimes called the fore loop of the cycle, while the omega to alpha transition is sometimes called the back loop. Resilience changes during these transitions. Resilience—the ability to withstand disturbance and still retain essential features of the system—is generally very high during the r phase and declines through the K phase.



The adaptive cycle is a very general representation. It does not apply to all types of systems. A system needn't necessarily progress through the four phases in the order described above. Other transitions are possible. For instance, a system could be in the r phase and experience an outside disturbance so profound—such as a large earthquake or global economic recession—that it goes directly into the omega phase, bypassing K. Other systems appear to go directly from the back loop to the K phase, with large, dominant corporations appearing quite early (this would be more true in social and economic systems than in ecological ones). While still others can oscillate back and forth in the fore loop—creeping towards high K and then falling back towards r—or the back loop. Some 'controlled' back loops, or back loops occurring at small scales, can skip the α phase—there is no real innovation, and no real surprise about what will emerge.

Finally, one should remember that the four phases of the adaptive cycle are general concepts. They can't be precisely defined, and different observers may perceive different phases at the same time in the same system, particularly if the system is near a transition (e.g., r to K or K to omega). But the phases do have well-defined characteristics, and being able to place a system in a particular phase, or being able to place it near a transition, is useful because it can aid in management decisions. In particular, the types of management challenges and the vulnerabilities the system will face, vary from phase to phase, something we will return to in later chapters.

Step 3.2

Cross-Scale Interactions: Influences from Below

As we've seen in a previous chapter, systems can operate on multiple scales of organization, from small to large. The notion of the four-phased adaptive cycle was also introduced earlier. Resilience theory suggests that this adaptive cycle operates at all scales of natural-resource systems, from the smallest to the largest. Leaves on a tree, for instance, are 'born', die, and appear again. In this case, the new adaptive cycle repeats the previous one. Individual trees can be born, grow quickly, and mature before dying, again following the four phases of the adaptive cycle. Forests will, over longer time scales, come and go, again frequently passing through the four stages of the adaptive cycle. This nested set of adaptive cycles from small to large is frequently referred to as a *Panarchy*—different from a strict hierarchy.

The resilience characteristics of any focal system are in large part determined by the interactions of scales across this Panarchy, from the focal system to coarser scales and from the focal system to finer scales. In this chapter, we focus on the finer scales. Finer scales can enhance resilience of the focal system when they are allowed to change so that innovation and novelty can be introduced, in a controlled way, into the focal system. They can reduce the resilience of the focal system if they are tightly linked, such that disturbances rapidly spread from one fine-scale component to the next.

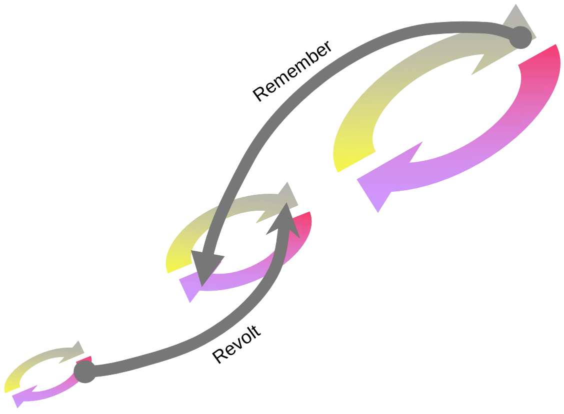
Some novelty, change, and uncertainty is inevitable in any complex social-ecological system. Back loop changes can be beneficial, as they can provide 'windows of opportunity' for resetting the system—formulating new relationships, allowing different resource uses and allocations, and/or fostering innovations in institutions and technologies.

Society, however, often wishes to avoid back loops at larger scales because these can be difficult to manage, potentially causing much human suffering and ecological damage. It isn't always possible to avoid these large-scale back loops; given enough time, any system at any scale will likely experience them, even when things are well managed. When the inevitable occurs, participants should make the most of the opportunity for reorganization and renewal. But wise management can, in many cases, minimize or reduce the number of back loops at the most socially damaging scales. This requires effective management of change at the finer scales of the system.

Revolt dynamics

One might instinctively conclude that avoiding a back-loop at the focal scale might require suppressing them at the smaller scales. This has, in fact, been the approach pursued by many modern management programs. One of the critical insights of resilience theory, though, is that avoidance of a back loop at the focal scale requires allowing back loops at smaller scales. Equally important, these back loops at smaller scales must be asynchronous—in other words, they must be managed so that they do not all happen at the same time. This means maintaining the different sub-systems at different phases of the adaptive cycle, or at least managing them so as to minimize the possibility that they will all be vulnerable to entering a back loop at about the same time. If the sub-systems are synchronous—all in the same or very similar phases of the adaptive cycle—the manager risks the back-loop dynamics growing and 'exploding' to the focal scale or even higher. This is known as a 'revolt' dynamic (we will learn about the 'remember' arrow in the next chapter).

Consider, for instance, the case of fire management in the Western United States. For many decades it was assumed that the best way to avoid fires at the focal scale—large tracts of forest covering tens or hundreds of square kilometers—was to suppress it at the smaller scales of forest stands or patches. Fires that did ignite—through human carelessness or natural causes—were quickly extinguished whenever possible so that they would not spread.



What was the effect of this strategy? Large landscape-level fires became more prevalent, not less. Why? In large part it was because most of the subsystems—most of the forest stands and patches—hit a high K phase at the same time, with lots of mature trees and the accumulated fuel load associated with mature patches. When a fire was accidentally ignited in one patch, the neighboring patch was also highly susceptible to fire, and sparks and embers were highly effective in spreading the initial fire into a much larger forest fire.

Now fire-management strategy is quite different. Fires at the patch or stand level are allowed to burn—managers often even purposefully set these fires. But they are carefully controlled and contained at the patch level. A 'mosaic' of stands of different ages and structures is created—a newly burned patch next to a mature patch next to a mid-successional (middle-aged) stand. This way mature stands that are highly susceptible to fire don't neighbor each other, and fires that start accidentally have a higher probability of being contained. (Note that even with this more effective management strategy large fires cannot always be contained. Prolonged drought, for instance, or pest infestations can make large tracts of forest susceptible to fire even if the mosaic structure—patches at different phases of the adaptive cycle—is being maintained. Wise management can reduce the probability of large fire, but not eliminate it.)

This management strategy may seem self-evident now—indeed, it has been practiced by many types of people for thousands of years—but one must not forget that these lessons about managing change were, at least temporarily, lost to some forest managers. The opposite notion—that suppression of change at smaller scales is beneficial for avoiding change at larger scales—is present in many other more complex natural-resource-management situations. This type of management seeks to tightly control systems, instead of allowing for natural and inevitable variability.

To reiterate, suppressing change at small scales creates a synchrony—sometimes called *hypercoherence* or *overconnectedness*—that can ultimately lead to all smaller-scale systems entering a back loop at about the same time, creating a back loop at the focal scale or higher. This is known as ***revolt***. In addition, the focal scale is most susceptible to a back loop when it is in a high K phase; that is also a phase in which the focal scale may most constrain the subsystems, forcing them to pass through adaptive cycles in 'orderly' and synchronous fashion. Thus, the focal scale may be most vulnerable to revolt dynamics when it is in a high K phase. Promoting asynchronous back loops at the smaller scales, on the other hand, avoids the hypercoherence and makes a revolt cycle—or a back loop at the focal scale—less probable.

Preventing back loops at the focal scale requires allowing them at finer scales.

Of course, a manager could also attempt to create hypercoherence if he or she were interested in creating a back loop at the focal scale. This might be necessary if conditions at the focal scale were untenable, and creating a window of opportunity for change were necessary. The challenge of this approach is that back loop dynamics cannot always be controlled, and the resulting 'new' system may or may not be what the manager (or society) desired or intended. Nonetheless, some preparations can be made for guiding back-loop dynamics—we return to this in section X.

The changes that result from asynchronous back loops at small scales serve resilience at the focal scale in another way. As we learned briefly in the previous chapter, the natural trajectory of many (but certainly not all) social-ecological systems is to push higher and higher into the K phase—with very high efficiency of resource use, relatively strong conformity, and fairly tight controls on structure and function. This type of efficiency can be worthwhile, allowing, for instance, maximum exploitation of resources for advancing human well being. But it doesn't come without cost. The high K phases are susceptible to internal and external disturbance that can push them into a back loop. When all resources are fully and efficiently exploited, for instance, there is no 'buffer' to utilize when an unexpected circumstance or crisis appears. Similarly, when there is high conformity and control, the ingenuity and flexibility needed to deal with a crisis may be lacking.

The focal scale is most vulnerable to back loops when it constrains the finer scales, forcing them to conform to a norm in a way that synchronizes their dynamics.

Societies and groups must then choose what 'balance' they wish to achieve between flexibility and conformity. Moving away from a high K phase at the focal scale may necessitate allowing some constant, smaller forms of renewal or innovation to become an integral part of the dynamics of the system. Back loops at subscales can be an important way to introduce this innovation. This is as true for social systems as it is for ecological ones—maintaining a vibrant city, for instance, may require allowing neighborhoods to grow, 'die', and reorganize. Similarly, maintaining innovation and flexibility in a corporation may require promoting new leadership configurations and responsibilities for employees.

The trick is in managing or coordinating these changes, or back loop cycles, so that only a few groups or areas are affected at any one time, and so that core components of the system remain operational. While there will be some suffering associated with passing through the back loop, the suffering can in part be alleviated by the resources available from those parts of the system remaining in the front loop. When everyone is passing through a back loop simultaneously, those sorts of rescue resources may be unavailable.

3.3

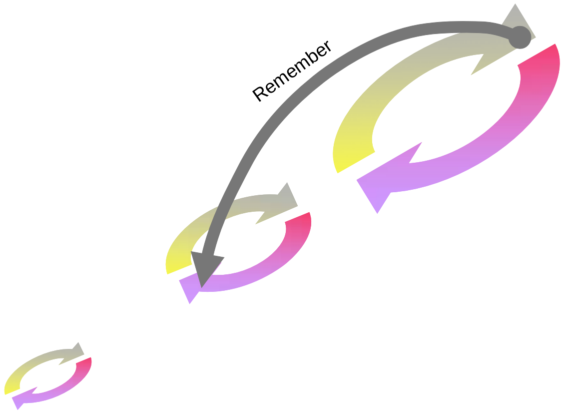
Cross-Scale Interactions: Influences from Above

We learned in the previous chapter that the resilience of any particular focal system we’re interested in—a managed forest, a grazing livelihood, aquaculture—will depend not only on the phase of the adaptive cycle the focal system is in, but will also depend on the phases of the adaptive cycle of the coarser scales (systems above) and finer scales (systems below). Resilience also depends on the way in which nested systems at various scales are interacting with each other. In this chapter, we focus on the interactions of the focal scale with the coarser scales.

Consider first the question of what determines whether, after a back loop, a very similar adaptive cycle will appear, or a fundamentally different one, Resilience theory suggests that the coarser scales can be critical in providing the ‘memory’ that allows the focal system to replicate earlier adaptive cycles.

Take, for instance, the case of a forest stand destroyed by fire. Will the ensuing stand eventually (after it has had time to grow) look much like the previous stand, or might it look drastically different? If there is an intact surrounding forest to provide an influx of new propagules (seeds), then the new stand will very likely replicate the surrounding forest. (This could either happen after the fire, or earlier, through an influx of seeds into the seedbank.) The intact forest (higher-level system) with its propagules serves as the memory for the focal system (the stand). If the surrounding landscape is highly fragmented, though, with many different types of ecosystems providing a source of seeds, it can be difficult to say which will get their first, or establish. There are still seeds that can potentially be thought of as sources of memory, but there is now more than one type of memory. The new stand may look like the old, or it may not.

Note that in the first case—a relatively homogeneous and intact forest—our coarser scale is likely in a K phase—a few dominant species occupying a large proportion of the landscape. In the second case—a fragmented and diverse landscape—the coarser scale is more likely in an r phase, or an r to K transition, or even a back loop. Thus *memory* is strongest when the coarser scale is in a K phase. In other words, if our focal system were to go through a back loop, we would most likely expect the new adaptive cycle to replicate the old when the coarser scale is in a K phase. Memory would be extremely weak if the coarser system were in a backloop, or very early in an r phase.



These insights extend to social, economic, and social-ecological systems as well. Consider another simple example—the dissolution and remaking of a household. This could happen through children leaving to marry, divorce, or death, to name a few. The new household that reforms may look very much like the previous one (nuclear family, extended kinship groups) or quite different. This is in part determined by the 'memory' of the culture in which the household is embedded. Are only a few household structures found to be acceptable, or are there many different forms that might be allowed (e.g., same-sex couples, collection of unrelated young adults and their children)? How strong is the culture in enforcing the preferred models? One can imagine political examples as well—after a revolution, for example, how many of the structures and forms of government are borrowed from earlier manifestations, and how many are truly new? Often (but not always) past experiences and traditional institutions will be important in determining the form and responsibilities of the new or reshaped government.

Strength of connections

This latter example illustrates a second important point—the strength of memory will not only depend on the phase of the adaptive cycle of the coarser scale, but on the strength of the constraints and connections imposed on the focal system by the coarser scale. The coarser scale may be in a K phase, but 'indifferent' to the trajectory taken by the focal system if many trajectories are possible or tolerated. If few trajectories are tolerated, and the coarser scale is strongly connected to the focal system, memory will be highly effective. If many trajectories are tolerated, and/or there are only weak connections between the coarser scale and the focal system, memory will be weaker and less effective.

Coarser scales provide the 'memory' during reorganization phases of adaptive cycles.

Note that effective memory isn't always a good thing. At times it may be desirable to break the patterns of past adaptive cycles and enter a new trajectory. The constraints from the top may hamper this—if new trajectories are desired, some weakening of the constraints visited from the top may be needed, or a greater tolerance for alternative trajectories may need to be cultivated. This can be true in ecological as well as social systems.

Constraints from above can also introduce 'hypercoherence' at the focal scale (see previous chapter). Breaking the constraints being imposed by the coarser scale(s) may be necessary.

Larger systems can constrain smaller ones through the types of subsidies that are provided. This is in both the ecological realm (such as water and nutrients along a flood plain), or in social realm (such as policies that limit types of practices. These can be both positive and negative influences.

The influences from coarser scales are sometimes overly constraining, reducing flexibility and resilience at focal scales.

At the same time, it is desirable to impose some constraints on tolerated trajectories—if any configuration is permitted, it means there is no common conception of rules, traditions, or norms. This can make it virtually impossible for large (or even small) groups of people to live together in social collections. Some constraint on the behaviors that are permitted will be required if society is to function effectively and efficiently. (We wouldn't, for instance, have to continuously renegotiate the rules for a group to work through this set of chapters and assessments. Some recognition of an acceptable process is required if the assessments are to be completed at all.) The desired 'balancing' of flexibility and stringency depends on the group or the culture, and on the social and ecological conditions in which that group or culture finds itself embedded.

This balancing of flexibility and stringency can however, be used to manage resilience. 'High K' phases are usually characterized by low flexibility/high stringency or efficiency. These high K phases are also vulnerable to being pushed into the back loop. If one wants to maintain the status quo, resisting a complete push towards efficiency at the expense of flexibility may be warranted. This can be achieved by allowing some diversity and innovation to be introduced from lower levels, as was discussed in the previous chapter. But sometimes the 'demands' or constraints from above prevent such balancing—the push is towards greater and more efficient resource use, for instance, reducing the ability to balance too great an emphasis on efficiency with some flexibility. Thus another important aspect of resilience lies in assessing whether the 'memory' imposed from above is overly constraining, or allows some experimentation, innovation, and flexibility while maintaining 'useful' forms of memory. We'll be evaluating memory and constraints in the assessments that follow.