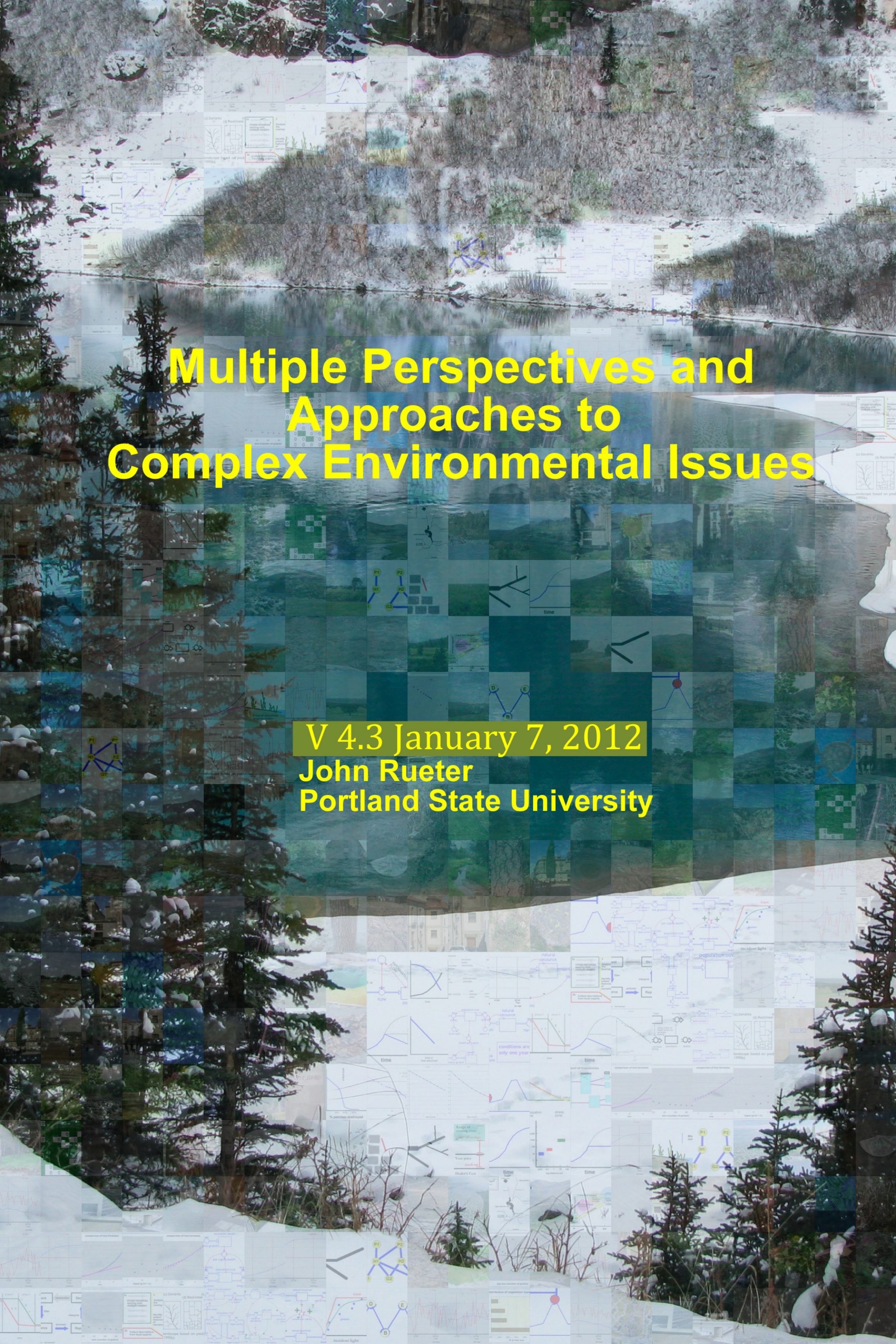

Multiple Perspectives and Approaches to Complex Environmental Issues

V 4.3 January 7, 2012

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V 4.3

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Notes for ESM 101 and 102

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NOTE:

Some chapters in this version contain sections of notes in outline form and three chapters are only outlines.

The appendices for this version are on-line at either:

http://www.johnrueter.com

http://web.pdx.edu/~rueterj/multiple-perspectives

Summary of chapters and assignments

Reading	**ESM 101**	**ESM 102**	**Status**
Preface	Week 1	Week 1	complete
Chapter 1: Introduction	Week 1	Week 1	complete
Chapter 2: Major concepts	Week 1	Week 1	complete
Chapter 3: Eight viewers	Week 1	Week 1	complete
Chapter 4: Patterns of interaction	Week 3		complete
Chapter 5: Node and arrow systems	Week 2	Week 2	complete
Chapter 6: Scale	Week 6		complete
Chapter 7: Networks	Weeks 5 & 7		complete
Chapter 8: Risk, uncertainty, and indeterminancy		Weeks 3 & 5	complete
Chapter 9: Games	Week 8		complete
Chapter 10: Accounting		Weeks 4 & 6	Outline
Chapter 11: Values and Worldviews		Week 7	Draft
Chapter 12: Multiple Perspectives Framework	Week 9	Week 8	Complete
Chapter 13: Innovation		Week 9	Outline
Chapter 14: Scientific Adaptive Management	Week 10		Outline
Chapter 15: Engagement and Entrepreneurial Approaches			Outline
Chapter 16: The tenuous path to sustainability		Week 10	Draft
Appendices			drafts
References			Complete

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- experimental approach to management
- depends on experiments, multi-scalar

Preface

My goal in writing this book is to help students of environmental science and issues to think more broadly about the problems they will have to participate in solving. Those problems are "complex" in the sense that they involve multiple interacting processes. They are also complex in another sense (that we will call "wicked") in that as more information is available, people change some of their values.

There are five principle components in learning about these complex environmental problems:

1. **Metaphors:** You need to have a repertoire of metaphors for complex systems. These will be added to the mechanistic and social metaphors that you use already. Complex metaphors will help you identify complex behaviors in other areas of study and suggest possible underlying structures and relationships that can lead to these types of behaviors.
2. **Experience:** You need to have direct and personal experience with real systems that are messy enough such that any single description or simplification can't possibly capture all the features of the whole problem.
3. **Simulations:** You can use simulations (such as multi-player games or computer simulations) to learn about the multiple possible paths and outcomes for these problems. Simulations are very useful to learn how the same system of components and processes can have widely different outcomes with only slight changes in particular conditions or parameters.

4. **Observe, collect data, and analyze:** You should observe and collect data from a system without the biases that comes from starting from general laws. This takes more time than simple lab exercises and requires justification for the effort.

5. **Relationships:** You will build meaning by creating relationships within your observations. These new relationships will suggest ways that you can further examine the problem. Graphic visualization can facilitate building this knowledge.

This book is an introduction to this approach and will guide you through the first three steps and provides a basis for extending your efforts to more sophisticated uses of simulations, data analysis and visualization.

Environmental "problems" are any mismatch between the current value of some part of the total human-nature environment and what it has been or could be in the future. It doesn't matter whether we are trying to enhance an ecosystem or fix one that was destroyed. What does matter is that these problems come to us as whole unit comprised of humans and ecosystems and the problems can't be reduced into independent parts (such as the human part and the natural part or the economic part and the social part). This claim (that they can't be reduced) is somewhat controversial but is an underlying theme of this text. It is also important that we engage in trying to solve authentic problems. We are not just interested in this for some purely intellectual reason. We (as environmental-minded citizens, scientists, managers or policy makers) are in a position where we have to do something and we need to make the best possible choices. Every time we try to move forward we will be facing many potential traps and surprises.

This book provides a framework for addressing problems that has three parts:

1. Look at very problem from several perspectives.

2. Analyze the problem using any approaches that might work. Do not discard an approach before you try it.

3. Combine and blend the results of what you learned from the individual perspectives.

This book provides eight different perspectives that can can start with. Each of these uses a limited vocabulary, focuses your attention on a few salient features, and uses one or two powerful intellectual skills. By attempting to use each of these techniques, you are probing the nature of the problem and the structure of the information about it. For example, if you had to describe a human activity by using the terms "competition", "score keeping", and "performance"; it would be easy to talk about sports but hard to discuss gardening. Each of the eight perspectives contains a set of tools for describing and analyzing problems in more detail. Thus, attempting to address a problem with multiple approaches serves as a heuristic process that will help uncover the salient features of the problem, the different structures of the information and potential tasks that might be worth more effort. For example, if you decided that "systems" view was productive way to describe part of a problem, the "systems" view also contains more sophisticated methods to model and simulate systems. Finally, in order for this framework to be complete, the results from all the different views need to be able to be joined back together. The multiple perspective framework does not require that all the views converge, as often seen in a discussion of sustainability as the intersection in a Venn diagram of social, economic and natural sustainabilities. One view probably can't represent all the important features of any real environmental problem. This framework also allows you to look for possible surprises or traps. A surprise is a change in the progression of the system that either changes the nature of the problem qualitatively as well as quantitatively, or changes the rules governing that system. A trap is the situation where it is easier to do something than to correct it later. Each of the viewers also suggest further, more sophisticated analysis that can you can pursue but that will be beyond the scope of this book. My purpose is to provide practice with the first two steps with each viewer and then some experience with combining views together.

This book is organized to present the individual "viewers" followed by a practice example or case study that illustrates how this viewer can be used. As you progress through the book, the previous viewers will be applied to each problem so that you will also gain experience in testing each new problem against the existing viewers. Additionally, after you have experience with a few of the viewers, the full framework will be invoked for evaluation of the problem from multiple perspectives. I think the importance of this approach is not in the details of any one viewer, but how they can all be used together, simultaneously in the overall framework.

A "lite" example of the entire framework can be obtained by reading:

Chapter 1: Introduction
Chapter 3: Eight viewers and the Framework (focusing on the framework)
Chapter 5: Stock and Flow Systems
Chapter 7: Relationship Networks
Chapter 9: Games View of Decisions
Chapter 12: Multiple Perspective Framework

As we learn more about interactions between humans and the total environment we are faced with many problems that we need to address. Whether we employ scientific technology, socio-cultural change, economic policies or other approaches to these problems, we need to be careful in employing any one type of solution or any fixed combination of solutions. We should remember that many of the problems we are addressing now are the result of past well-intentioned "solutions”. These include such advances and projects as cars, levees in the Everglades, and CFCs. We need to be humble as we pursue solving our current problems in way so that they contribute to progress without themselves creating further problems. One of the insights that I hope you will gain from this book is how to use multiple approaches to look for solutions that originate in the middle zone of control, where many different small factors interact, and that allow many of us to act in concert and share our efforts to create a resilient solution.

PART 1: INTRODUCTION TO THE MULTIPLE PERSPECTIVES APPROACH

Chapter 1. Introduction

1.1 Being part of the solution

The reason to study environmental issues is to be part of the solution. We all want to help solve environmental problems either as scientists, policy makers, as citizens or in some combination of roles. Our motivation for solving these problems is simple and pure; we want a better life for more people without wasting our resources and spoiling the planet. But in our drive to solve these problems we need to be thoughtful and not cause other problems along the way. The agricultural philosopher Wendell Berry (1981) explains that there are three ways to act on a problem. First we can really not solve it all, second we can solve it in one place by pushing the problem somewhere else, and third (and only real solution) is to solve the problem in the context and pattern of its origin. Although it may seem obvious that the first two don't really work, it is not easy to solve any significant problems in the pattern. How do we know what the total context for the problem is? Maybe we are missing a piece of the overall picture? Maybe we will find out later that our solution just moved the problem elsewhere. For example, the purpose of dairies is to provide milk but along the way they create much more cow manure than milk. One way to deal with this is to flush the manure away (causing a problem somewhere else). Another method is to put the manure into a high-tech treatment facility (turning the dairy farmer into a sewage treatment operator). A third way, suggest by Berry, is to have a dairy of just the right size such that the amount of manure generated can be composted and spread back on the grazing lands, thus keeping with a pattern of ecological cycling.

This book addresses the challenge of identifying environmental problems and placing them in multiple contexts. We will do this in a very structured way. First, we will review the central concepts in Environmental Science. Second, we will look at example problems with simplified and constrained intellectual tools that I call "viewers". In the beginning these viewers are simple to use and limited in scope. You can practice with each viewer on problems that have been designed to illustrate the benefits and limits of each particular approach. Third, we examine problems from multiple viewpoints; each view provides some overlapping information but also some unique perspectives on the problem. Finally, after practice with individual viewers and comparing them, we will discuss how this strategy helps us to solving problems in the larger pattern or global context.

One of the purposes of an environmental science course is to create scientifically literate citizens. The responsibilities of citizens have continued to grow. As problems become more complex, with many independent parts of the problem that need to be synthesized, citizens need to be able to see how the problem affects many scales including larger contexts and longer time scales. They also need to be able to make decisions on limited and imperfect data. It is often necessary to be able to make decisions under conditions of uncertainty or ambiguity. This problem is exacerbated as new technological problems meet traditional government institutions. It is almost impossible for scientists to stay abreast of progress in their own narrow disciplines let alone an elected official or administrator keeping up with all developments. The highly technical nature of some aspects of environmental science (for example the debate on the toxicity of pesticides) requires an understanding of multiple disciplines and several areas outside of normal academic life. Just as being "literate" in English doesn't mean you know all the answers, being environmentally literate is more about knowing how to address the question and the ability to draw on your experience and outside information resources as appropriate.

Sidebar:
Are we dumber than we used to be?

Rapid change in technology and the access to energy has created a situation where new discoveries, inventions, innovations, or processes can be implemented on a global basis almost immediately. Do we really know enough to be able to make decisions about these new processes?

For example, consider the invention of chloro-fluoro-carbons, "CFC"s, that took place in an industrial research lab. The rapid adoption of CFCs into refrigeration led to their worldwide use. After a while it was discovered that these chemicals were changing the balance of ozone production and decay in the upper atmosphere and could lead to dramatic and damaging increases in UV radiation. Essentially we were ignorant of the effects of CFCs and it took many scientists many years to accumulate data to show the potential damage. A novel chemical put into the industrial stream, had created a gap in our knowledge, i.e. created ignorance.

It is argued that we may be able to create new products faster than we can test them? Are we producing more uncertainty and ignorance that we can handle?

We will address this further in Chapter 13.

Citizens need to know at least three things to be literate in environmental science:

1) They need to be able to sense and become aware (from the data, descriptions or personal observations) that there is an environmental problem,

2) They need to be able to key in on particular aspects of the problem that suggest possible approaches for solving the problem, and

3) They need to know that they are supposed to act, either to get more information or to participate in solving the problem.

Thus, citizens need to be able to "understand" environmental problems, using Perkin's (1998) definition of understanding. To understand is to be aware, to sense a situation and then to do something about that awareness. This definition of "understanding" is very active; it is not simply a mental image of a problem. Just as with the infinite shampoo loop (wash, rinse, repeat), understanding is a never-ending process to build context around observations and actions.

Humans have unprecedented power to change their environment. We have harnessed energy sources and can direct this energy using a range of powerful technologies. The power of science and technology should be balanced with responsibility, but it can be argued that the changes (progress) in scientific and technological tools have outstripped the intellectual, social, institutional, and ethical tools to do the job. For example, the possible genetic engineering of humans challenged the ability of people to make novel decisions. Similarly advances such as nuclear power, genetically modified seed stock, and artificial hormone pesticides have outstripped human problem solving approaches for solving these in the whole pattern. A very real part of the problem is the "advances" themselves. Technology can only create part of the solution. We only create the machine or the chemical and don't bother to simultaneously disseminate information and create the institutions that are necessary for using these tools responsibly. For example we live in a country where anyone can buy a chainsaw, almost anyone can buy a gun and some bullets, or on a whim you can go to the store and buy a gallon of Roundup for home use. All of these items are both useful and potentially very destructive to the environment.

Sidebar: What do we mean by "progress" vs. "providence"?

Progress

moving forward, onward, advance

the advance or growth of **modern**, industrialized society, its technology, and its trappings

Providence

The **prudent care and management of resources**.

The careful guardianship exercised by a deity.

A manifestation of divine care or direction.

(from Wiktionary)

These are closely related to the positivist ideas of what is modern. Norgaard (1996) claims that "modern" is also wrapped up in the assumption that science brings progress. So, progress and modern are reinforcing concepts. We need to re-evaluate our assumptions about what we really want.

Our goal should be no less than to learn to live in a way that leads to permanence, health, beauty and peace. These "lofty" goals are value laden and require more sophisticated approaches than just measurement of simple costs and benefits. A serious challenge for environmental science is face the larger picture of the personal and societal values that go beyond just the economic values and rational decisions. As Schumacher (1973 page 20) wrote:

> "Scientific or technological "solutions" which poison the environment or degrade the social structure of and man himself are of no benefit, no matter how brilliantly conceived or how great their superficial attraction. Ever-bigger machines, entailing ever-bigger violence against the environment, do not represent progress: they are a denial of

> wisdom. Wisdom demands a new orientation of science and technology towards the organic, the gentle, the non-violent, the elegant and beautiful."

Some of the environmental problems that will be presented and studied in this text seem overwhelming in their scale and power. Large scale, high-energy intensity, complicated social systems and the inertia of existing technology are the defining characteristics of the current environmental crisis. Our society definitely has an "energy crisis" it is because we have been "solving" all of our problems by using too much power. Applying more energy and at a larger scale can actually increase the uncertainty or indeterminacy in the system, applying more effort pushes these systems further away from simple stable states (Adams 1988). For example, using more powerful tools and machinery in the forest can lead to qualitatively different outcome than simply getting the same job done more quickly.

When we think about the juggernaut of globalization (Giddens 2003) or the seemingly intractable political issues surrounding global warming, it may seem as if individuals could have no real effect on controlling or reversing and destructive activities and trends. The theme of this book is to promote that contrary vision, i.e. that every individual can play a powerful role. This is not based on just optimism, but follows from the multiple views approach. Applying multiple views to the question, "how can we contribute to the health of our environment?" results in an understanding of how individual actions can support feedback controls, lead to changes in a network, aggregate with other individual actions to lead to emergent changes at larger scales. In our society there are people who incorporate sound environmental principles into their every-day activities. If these people lead their innovative lives in a visible manner, other people will adopt and adapt their ideas. These relationships of creativity and imitation are not just important in fashion, music and the arts, and in mundane, everyday activities. Processes that mix ideas throughout our culture are key to creating a viable society (Toynbee 1946). Each of us are involved every day in this process of creating, innovating, and adopting new ideas that relate to sustainability. Our progress toward a sustainable future will include technology of course, but that technology will be guided and controlled by the social structures that we develop as we use it. Each of us can contribute to a sustainable future by gaining a better understanding of environmental problems from multiple perspectives.

1.2 Major Problems that are addressed by Environmental Science

Environmental Science as a discipline has historically identified problems in which there is a science or technology component and policy alternatives. Related disciplines, such as Environmental Economics, Environmental Sociology, and Environmental Policy would address many of the same problems with a different emphasis. These connections will be explored later in this text.

Two lists of problems are presented here for comparison. The first list is from Industrial Ecology (Graedel and Allenby, 2003) and a second list that I constructed. These are just two possible ways to sort out problems from a large selection of valid lists of problems and environmental crises. Every problem in both of these lists demonstrates that problems occur over a wide range of scales, they involve human impact and technology, and each has scientific, technological and social dimensions.

List 1: Graedel and Allenby (2003) prioritized by severity

- global climate change
- human organism damage
- water availability and quality
- resource depletion: fossil fuels
- radio nuclides
- resource depletion: non-fossil fuels
- landfill exhaustion
- loss of biodiversity
- stratospheric ozone depletion

acid deposition
thermal pollution
land use patterns
smog
esthetic degradation
oil spills
odor

List 2: List of environmental problems that interact interact with each other. The list is not ranked by importance.

population growth and human consumption
habitat destruction, loss of natural capital, pollution
climate change
energy use, resource consumption and side effects
agriculture/forestry/mariculture processes and fundamental basis
depletion of water resources
urbanization that leads to unlivable conditions
air pollution
loss of biodiversity

Other lists or taxonomies can be created for example that focus on the scale of the problem (local to global), potential costs to address, or types of technologies that will need to be employed to address them.

1.3 Values as part of environmental issues

Scientific environmental management deals with problems. A problem is situation in which we have judged could be better or needs to be fixed. Thus even the idea of an environmental problem includes a judgment or decision relative to what is and what could be. Some scientists argue that science should be objective and not include values into their work because it might bias the results or sway the research in some subtle manner. This is definitely a cause for concern and there are times when science should be done as completely objectively as possible (such as in lab trials for a drug or pesticide or when developing a new method). But in environmental science and management the larger questions (i.e. larger than just one set of lab experiments or development of a new method) are problem driven, not “pure” or curiosity-driven research.

1.4 Decision Processes

There seems to be a common misperception that environmental decisions would be easy if we just had more information, if we could just "set the right prices for incentives" or just pass a law. There are certainly some cases when more information could be valuable and might even help make decisions. However many environmental problems either won't be helped at all by more information or the cost of getting the appropriate new information would be more than just paying to solve the problem. An example of how people have different ways of valuing an environmental condition is when one person sees a dangerous mosquito-ridden pond and the other sees a bio-swale that cleans up road runoff. Information either may not help or the process of collecting information will take too much time or money to actually contribute to the solution of the problem. For example, should we dump a new type of chemical that we know is toxic into streams? The best guess based on previous work is that we should avoid adding a novel toxin. It might be better to spend research money on finding an alternative compound for the user, rather than to characterize the amount of damage that would be done.

Environmental problems fit into four loose categories (Cunningham and Sato 2001) (Table 1-1). Some problems might fit into one category easily clear but others might be a little fuzzy. These four categories are:

> **Easy Problems:** We can apply effort or allocate some resources to a problem. The proposed solution will return benefits to everyone. For example, reducing lead in gasoline or house paint is a simple problem with a solution that is good for everybody.

Complex/Information Problems: We need more information to be able to decide what action needs to be taken, but it seems as if a solution could be reached that would benefit everybody. For example, if we do more study on habitat restoration practices, we should be able to use the same amount of money to restore more damaged habitats more effectively.

Community Value Problems: There are simple solutions but they are not equally beneficial to all participants, some people or groups will get a better deal than others. These problems often require appealing to peoples' ethical principles to reach a solution. For example, water resources may need to be shared by people, who would each do better individually to use as much as they can, but better off as a community if they cooperate.

Wicked Problems: Even if we were to get more information, the possible solutions seem to have uneven benefits. Wicked problems also change because as more information becomes available, peoples' values change. This type of problem requires community building that can reach a compromise solution and social capital that can endure the stress of the process. A good example of a wicked problem is the question of nuclear power; there are good aspects, bad aspects and these are always changing as the technology improves and as we learn more about the risks and impact of all the options (i.e. fossil fuels, nuclear, biomass, and others).

Table 1-1. Types of environmental problems and decisions (adapted from Cunningham & Saigo 2001).

information demand	alignment between costs and values	
	good	poor
simple	EASY regulations	Community Value community rules
complex	INFORMATION more research	WICKED political processes

Later in the text (Chapter 15: Engagement and Entrepreneurial Solutions) we will return to looking at actions that can be taken depending on the type of problem.

The other major limitation to our ability to solve problems is that we don't know everything; in fact we may not be able to know enough about a problem to ever "solve" it. A commonly held belief (in America) is that if we study a problem more we will be able to develop scientific and technical solutions to our environmental threats. Although this may be true much of the time, the weakness with this assumption is that all of the systems that we are dealing with are complex (composed of interacting sub-systems) and they may be changing faster than we can study them. It is very possible that the effort required to study a system is greater than the effort required for plausible solutions to the problem. It is also possible that our actions won't have a detectable impact for a while until the problem is so entrenched that it would require an extreme amount of effort to correct it. These are the essential issues (rate, irreversibility) when facing threshold effects for environmental impacts. For example, it took a long time after DDT was introduced for us to observe the effects of bioconcentration in the food web and for corrective actions to start. Even many of the thoughtful, well meaning, and well studied positive actions that humans have taken have backfired or lead to unintended consequences. We should probably rely more on our ability to avoid impacts and problems than depend on our scientific and technological approaches to fix the damage.

1.5 The Role of Environmental Science

Science, technology and reason haven't always been combined flawlessly in the past. Certainly no argument that relies exclusively in the domain of scientific knowledge can ever justify why scientific thinking and approaches should dominate our decision processes in the future. Environmental Science is no different. Our discipline needs to move forward with all the other scholarly areas into post-modern, integrated ways of thinking and acting (Harvey 1990, Norgaard 1994). Fortunately as a relatively new area of study, we have the opportunity to incorporate many approaches and meta-disciplinary tools.

One of the main activities in science is to build models and relate the models to the real world. The progress of science in the Western tradition has moved from focusing on observations to allowing for more interpretations (Linstone 1981).

Table 1-2. Historical view of the match between empirical evidence, theory, social constructs and truth

Life span	Proponent	Description
1632 to 1704	Locke	empirical; agreement on observation and data
1646 to 1716	Leibniz	theoretical, truth is really in the analytical description, the truth doesn't depend on any particular data set
1724 to 1804	Kant	theoretical and empirical data complement each other, truth is in the synthesis, the synergism of multiple models
1770 to 1831	Hegel	dialectic confrontation between models or plans leading to resolution
1908 to 1961	Merleau-Ponty	reality is defined by the currently shared assumptions about a specific situation

It used to be that observations were held to be true and that these didn't depend on theoretical considerations (Locke). Then we progressed (or changed) to looking for "truth" in elegant and simple laws that described the universe and considered that the raw data from the real world might be flawed by measurement error (Leibniz). More recently we considered that the empirical and analytical models were complimentary and that the best outcome was an elegant model that "explained" the data most parsimoniously (Kant). Currently, there are some who still hold this view while others are working toward a post-modern view (Harvey 1990) in which there may be multiple forms of the data and multiple models and that these forms don't necessarily have to converge to provide one single meaning. Post modern is often misinterpreted as meaning that there are no absolute truths, but a better way to understand it is that there are no universal ways to evaluate a claim as being true. Modern environmental science is focused on solving problems and, as a discipline, is very optimistic toward being able to contribute. It may be simply this optimism that separates the underlying philosophy of environmental science from post-modern who maybe more fatalistic in their rejection of efforts to look for enduring truths. This may seem like a philosophical detour, it is important to consider that as social, political and economic thought becomes more advanced, contemporary environmental science needs to keep up and scientists should be able to make arguments that are valid in and relevant to these other intellectual areas.

*

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New paragraph and Table 1.3

Scientific Adaptive Management is a philosophically coherent method to address these problems that is more suited to environmental, problem-based issues than the scientific philosophies listed in Table 1-2 above. This approach focuses on identifying problems and manipulations from management are experiments. Scientific Adaptive Management will b explored in more detail in Chapter 14.

New paradigms may be emerging

Transdisciplinary (multiple definintions: work across sectors, problem definition benefits from stakeholders and others)

Because other sectors include value, environmental science must deal with this also

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As you will see, this text presents multiple ways to view problems and makes it very clear that these different views should provide some information that will converge and some that won't. There will be other insights and understanding of a problem that you can only achieve by using very different, even conflicting or ambiguous, approaches. The natural world, human activities, and our environmental problems are not tidy. Our problems our often il-defined, and require cognitive flexibility to understand them and simultaneously place them in different contexts (Spiro et al 1999). Science provides some very powerful intellectual tools and often these scientific tools are accompanied with technologies that are also very powerful. Unfortunately the environmental problems that we face are going to require science and technology in a social and ecological context. The challenge for each of us, as scientists, citizens, and policy makers, is to learn how to "solve in the pattern" (Berry 1981), i.e. to solve the problem in its larger context without creating other problems along the way.

Multiple Perspectives V4.3

Chapter 2: Major Concepts in Environmental Science

2.1 The importance of central concepts

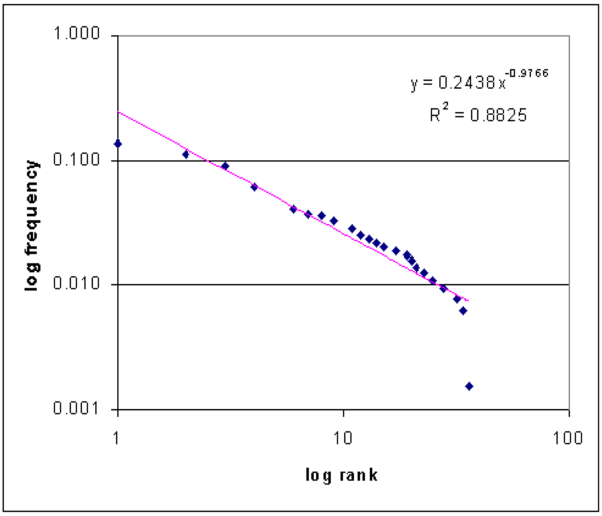
This book is for people who have a general understanding of environmental science. This may be because they are students taking (or have taken) an Environmental Science or Environmental Studies class. Alternatively, many people are very aware of environmental problems and have good working vocabularies for the major terms. There are terms and sets of concepts that are very important because they connect across the sub-disciplines of environmental sciences. These may be concepts that connect population growth to human impact or the concepts that describe the tradeoffs between using different resources (such as land, water, energy). I have had students who knew much more than I did about particular areas of environmental science, such as plant diversity, but drew value from the course by being able to connect their knowledge to other areas of the discipline, such as water, energy, and land resources.

For the purposes of this book we are going to use "vocabulary" to mean words and their definitions. Words may have more than one definition in standard use. A "concept" will be a simple idea in a particular context that can be described and discussed using the vocabulary. For example a definition of the word “energy” could be "the ability to do work". The concept of energy would be how this idea of doing work (force over a distance, or force against resistance) relates to the ideas of human use, fossil fuels, inefficiency, renewable sources, and other ideas. You can memorize the definition of vocabulary words and repeat them back, but you have to build knowledge of concepts by making these relationships for yourself.

I have used three different methodologies to developed lists of concepts that are useful. First I examined the terms used in several different introductory textbooks (Section 2.2). I did this by looking at the index but also looking for the terms on a page-by-page analysis of several sections. The second list was created by starting with six seed terms or questions that come from different areas of environmental science (Section 2.3). A concept map was generated for terms that are linked to a full description of this problem. The third list was created by sorting through key terms in the case studies that are presented later in this book (Section 2.4). These three approaches showed some shared key terms that are listed in the following table. (The full lists are presented in Appendix 1.) The purpose of this analysis was to be able to show that the cognitive tools that we are using can be applied to the full range of concepts covered in this book.

2.2 Textbooks and the structure of knowledge in the discipline

Information and its organization in textbooks represent each author's version of the structure of the discipline. There are many different textbooks on environmental science/studies that provide good introduction to the range of concepts and illustrate how these are related. Introductory textbooks must, by design, contain a wide range of concepts and only devote a limited space to these. I analyzed the structure of the concepts in one popular text and found that rank and frequency of concepts (as evidenced by of key words) are related in a log-log manner. This pattern is evident in many other works such as Joyce's Ulysses, and indicates that common words are used very frequently and uncommon words are used much less frequently. The ratio between rank and frequency remains remarkably constant over a broad range of rank. For example the change in frequency going from the 10th to the 11th most used words would be similar to the change in frequency going from the 100th to the 101st ranked words. This is a "fractal" pattern (see Chapter 3). This pattern in the ratios results from the writing style of describing new concepts by always using a common term to set the context for a more rare, more specific term. Thus each time a specific and rare term is introduced, it is surrounded by more common terms to provide context.



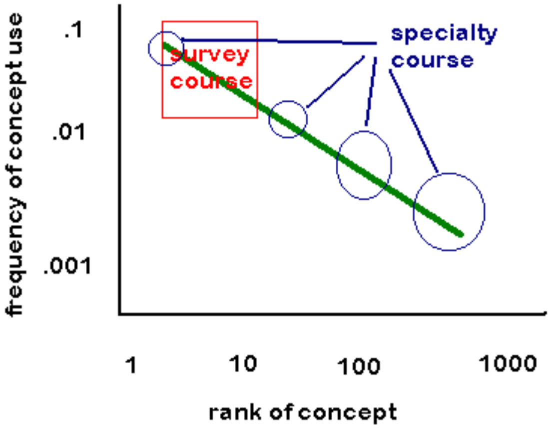


Figure 2.1 Frequency of use *vs.* rank diagrams for vocabulary terms in an environmental science text (a) or (theoretically) a curriculum of different courses (b).

The underlying message from this analysis of structure is that you really need to know the most common words and that as you learn more specific terms, you need to link them back to more common terms to fully integrate that term into your functional, working knowledge.

2.3 Generating a list from seed concepts

A useful way to explore how concepts are related is to create a map of vocabulary, facts and simple concepts that you would need to understand a particular problem or phenomenon. Pick a starting concept and then determine which other concepts or ideas you would be prerequisite knowledge for that concept or what other concepts this might lead to. For example you might pick the "precautionary principle" and then start by linking it to other ideas (Figure 2-2).

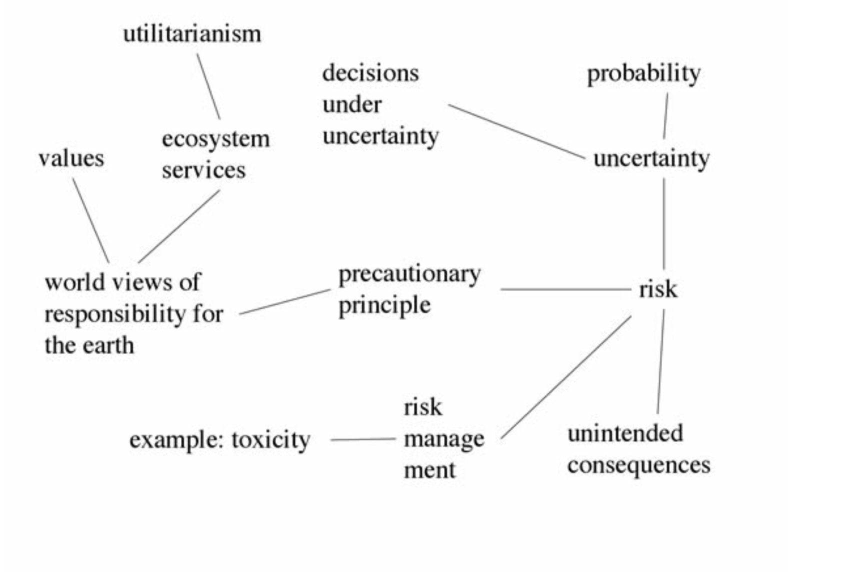


Figure 2-2. A concept map used to generate a list of related concepts to "precautionary principle". Only the first three or four levels are shown. A more elaborated map is shown in the appendix that has almost 50 linkages and expands out from the precautionary principle.

In addition to the precautionary principle, five other starting seed concepts are used to generate maps. There are almost 300 links shown in these diagrams, which show the relationship of the major terms and concepts. See Appendix X: Table Y: Concept lists generated from starting seed concepts.

- precautionary principle
- tragedy of the commons
- Hubbert bubble
- technology side effects
- 1st law of thermodynamics
- Why do humans pollute their environment?

Again, each of these maps is only one way to elaborate the linkages to other terms. There are endless ways that these concepts can be linked. The important point here is that we can generate more diagrams or look at the diagrams that exist and see that all of these concepts are connected in someway. Learning these concepts is more than to just memorize the definition, but to understand how each concept, vocabulary word or example is connected to the other terms. It's like a game of Kevin Bacon's Seven Degrees of Freedom. You can see that crucial, central concepts will be linked even when you start from very different seeds. Common and central concepts will show up very often where as specific examples may only show up once.

2.4 Concepts central to the case studies presented in this text

Based on the exercises presented above, a list of central concepts, vocabulary words and examples has been generated. This list is given in Appendix 1.

*

new comments

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2.5 A note on using Wikipedia or Encyclopedia of Earth to lookup concepts

Wikipedia (http://wikipedia.org) has several advantages and disadvantages as a source of environmental information. The main advantage (which is not trivial) is that anyone can access Wikipedia. Given nearly ubiquitous web access (through web-enabled phones, iPads, portable computers, etc.) there are more and more places where you have access to this resource right now and for free. If you are connected to the web, you can think of Wikipedia as almost a type of concept "spell-checker". If in-doubt, you really should use your spell-checker but you can't just accept every word change that the spell-checker suggests, nor can you trust that your spell-checker caught misspellings that lead to legitimate words.

Many of my colleagues don't like Wikipedia because there is no ultimate authority or process for the final verification of an entry. This is a legitimate complaint that is handled in academia by the use of a range of peer review processes (from blind review to committee reviews). For research papers and student work that are supposed to rely on primary resources (i.e. peer-reviewed journal or other publications) I think they are correct to discourage reliance on this quick-search source.

To address this limitation of Wikipedia, Encyclopedia of Earth (http://www.eoearth.org/) has a large number of short, peer-reviewed articles on environmental concepts. The articles are solicited based on a list of topics that is also under editorial control. This has the promise to be a very valuable resource but is still growing and has many fewer entries than Wikipedia.

I feel that Wikipedia has a legitimate role in learning about environmental science. No source is as broad as Wikipedia or as up-to-date. Terms that may take years to reach the glossary of a standard environmental science text (because of the writing, editing and production cycle) can show up almost immediately on Wikipedia. For example, the concept of Reducing Emissions from Deforestation and Destruction (REDD) were being discussed in the national press several years before these were addressed in any introductory environmental science text. Additionally many of the concepts that I have examined show links to other concepts, creating a valuable context for that term. The process of building this net of interactions is an example of probing these academic areas for the structure of the information, i.e. how concepts are related.

Another valuable concept in Wikipedia is to identify ambiguous concepts and to direct the reader to different meanings in an attempt to disambiguate these terms. A good example of this might be if you searched for "mustang". You might get information about the car or about the iconic feral horse of the West. Wikipedia attempts to sort this out, whereas Google mixes the search hits together (after the paid links) and most environmental textbooks would only address the wild horse.

2.6 Characteristics of useful of information

Environmental science doesn't have a central organizing principle that helps define the discipline, such as the Periodic Table, Newton's Laws, or Darwin's theory of evolution. Instead it is incumbent on all of us to be very aware of the ill-defined nature (multiple competing contexts) of all information that we gather and use. The process of placing information in context is essentially creating the network of relationships that give individual facts any value. Because of the way information is used and created it will have several characteristic dimensions of quality:

- the level of reliability
- authority of the source
- availability
- timeliness

Often the best quality will require tradeoffs between these characteristics. We may have to rely on current information that is moderately reliable and from an authority of moderate reputation but currently available to our organization to make a decision on how to proceed right now. There is often limited time or money to get the highest quality data from the most recognized authority. Federal agencies have been instructed to use the "best available information" which means the best of the information that is currently available (NRC 2004). This has been used to clarify that environmental agencies are not required to do more research before they make a decision. These ideas will be discussed more in later chapters (Chapter 8: Risk, Uncertainty, and Indeterminacy, Chapter 9: Games, and Chapter 14: Scientific Adaptive Management). Understanding the structure of the information, i.e. how concepts are related, in the discipline helps us use the best possible total quality of the information to make difficult choices.

Chapter 3 - Eight Viewers and the Framework

3.1 There are many ways to look at problems

The information needed to address any real environmental problem comes from at least several disciplines. Environmental scientists, managers and policy makers are required to use many tools and approaches to analyze problems because any single approach only looks at limited aspects of the problem. Thus, it takes multiple approaches to really see and address any environmental problem.

It is effective to learn how to use and practice individual approaches on example problems. This is will allow you to better understand the characteristic strengths and weaknesses of each approach before you use several in concert.

3.2 The eight "viewers"

We will use each of the following approaches with example problems during this book. The explanation for each of these ways to view the problem will be introduced in a simple, step-by-step manner. This simple start is for the purposes of this course and clarity. Don't be lulled into thinking that these tools are this simple or limited. Each of these approaches could be expanded to any level of sophistication and experts in many discipline use powerful extensions of these initial approaches.

There are eight viewers. Five of these are preliminary steps in analysis. These approaches help identify and separate of parts and characteristics of an environmental problem. The other three support decision making. These approaches help identify what type of decision you will be making and what information will be required. All eight are recombined in a framework that demonstrates how the extra work it takes to intentionally look at problems from multiple perspectives pays off.

A chapter will be devoted to each of these viewers. Each will be described in detail later and an example case study provided for practice. Below is a snapshot of what each viewer entails; a list of the steps to start using the viewer, a potential challenge for each, and several examples of how they are used.

Each viewer is useful for initial study of a problem. They are also a useful heuristic approach. This means, you can attempt to use the initial steps for each viewer on a problem to see if that viewer could be useful in addressing that problem.

Patterns and Metaphors (Chapter 4)

Observed spatial and temporal patterns are compared to a large repertoire of patterns that are known to have been generated by complex interactive processes.

Initial steps include:

- Discover patterns in primary observations or collected data.
- Describe these patterns verbally, graphically or with mathematics.
- Use the observed pattern to make hypotheses about what the most likely causes or important components.
- Consider possible solutions based on the pattern and hypothesized causes.

Challenges:

Just because you find a similar pattern in the catalog to the one you observed doesn't mean that you have identified the cause or mechanism of the observed pattern. You can't prove that one particular mechanism caused your pattern from the similarity. It is usually impossible to find a single cause that is forcing a complex system to demonstrate a pattern.

Examples:

- The geographical patterns of acid rain input, low pH in watersheds, and the death of trees are used to argue that smokestack emissions in Ohio are damaging forests in New York.
- The population size of rodents demonstrates a cycle. The hypothesis is that this general pattern observed is likely to be related to either 1) seasonal driving factors or 2) a predator-prey interaction.
- The decrease in birth rates as nations becomes industrialized and wealthier (the “demographic transition) is a pattern that results from complex interactions between

women's rights, education, employment opportunities, and ***.

See http://web.pdx.edu/~rueterj/courses/objects/metaphors.html

Figure 3.1 Erosion that forms a network of streams shows a fractal pattern that can be analyzed by comparing the length of the streams. The exact pattern can't be predicted, but the characteristics of the fractal relationship can be.

Stock and Flow Systems (Chapter 5)

A good stock and flow systems description of an environmental problem can help identify the major processes and potential for control or runaway feedback or traps.

For treatment of traps refer to:

http://web.pdx.edu/~rueterj/courses/objects/systems-view-of-traps.html

Initial steps include:

- Identify the major reservoirs of energy or material in a system and link these with flows.
- Describe the boundaries to the system being studied.
- Describe how the flows are controlled in, out and within the system.
- Use the system model to describe current conditions and hypothesize about future directions.
- Focus on the potential for positive or negative feedback loops within the model.
- Use the model to explore different conditions or controls and base decisions on these predictions.

Challenges:

The flows have to strictly match the content of the reservoirs to faithfully represent the system. This requires being clear with units of measure and mass or energy balance concepts.

Examples:

- Human birth, death, immigration and emigration rates all contribute to changes in the size and distribution of human populations. A decrease in the death rate in a country can have an explosive effect on the population unless balanced by a decreased birth rate or changes in immigration and emigration rates.
- Global climate change may lead to the melting of high-latitude glaciers, which in turn could increase the absorption of solar energy at those latitudes, leading to

faster melting. This positive feedback loop could be a crucial process to understand well for a prediction of global climate thresholds.

A simple example systems view of natural resource harvest might be to consider the growth rate of trees, the removal of trees for forest product use and the loss of tree growth due to the harvesting process. This loss of growth rate could be due to soil compaction, tree damage, and other factors that would be expected to increase as the intensity of harvest increases. We could represent this with a diagram (shown below) and discuss the relative strengths of these controls and also consider what other features should be added to more adequately describe this system to meet our needs.

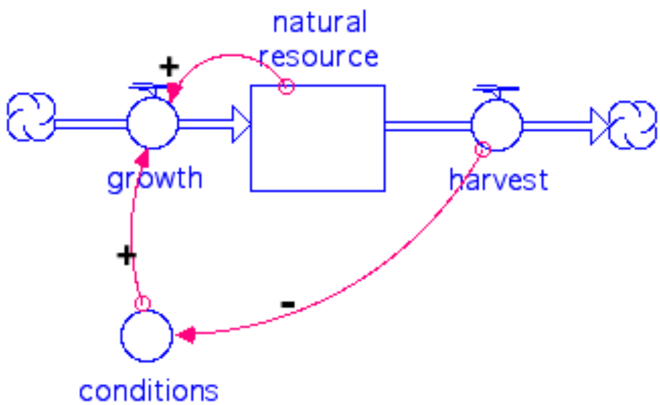


Figure 3.2 A stock and flow diagram that shows how harvest rate can degrade the natural resource by decreasing the growth rate.

Scale (Chapter 6)

There are many features of the environment (such as lakes, mountain ranges, cities) and processes (such as river flow, erosion, population growth) that occur over a wide range of time and space scales.

Initial steps include:

- Characterize the time and length dimensions of objects and processes in the environment.
- Assess the texture of an environment by determining the size and distribution of objects (such as small rocks to boulders).
- Identify cross-scale processes of interest.

Challenges:

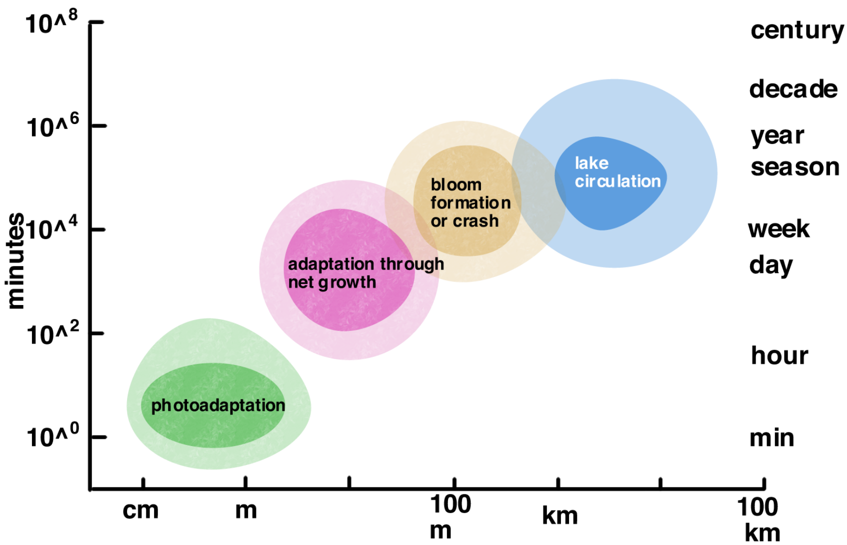
It is a common misunderstanding that large processes are just made up of a bunch of smaller scale processes and that if you understand the small scale, you can just aggregate these processes to understand the larger scales. There are distinct processes that only happen at particular time and space scales. There are also emergent behaviors, small scale behaviors combine to create something that is fundamentally different (qualitatively and quantitatively) at the larger scale.

Examples:

- Lakes are often studied and managed at a whole lake scale for periods of several years. However in many of these lakes the crucial biological processes (such as harmful algal blooms) happen in just parts of the lake over time periods of months but the forcing processes eutrophication are on the scale of the entire watershed over decades.
- The description of biodiversity depends on assumptions of the time scale and geographic extent such as: the diversity of birds in a city park, the survival of bird species throughout their range, and the continued evolutionary adaptation of birds that inhabit this range.

A "Stommel" diagram is one of the best ways to visualize the range of time and space scales that are involved. By representing this in on log scales, it allows the representation of a wide range of values over five to six orders of magnitude.

Figure 3.3 Time and space scales of processes in Upper Klamath Lake.



Network (Chapter 7)

Network analysis focuses on the relationships (of pretty much any kind) between nodes, cells or agents. This approach is much more flexible than the systems approach because many more types of relationships can be included. A network analysis can be used to understand the behavior of complex systems such as resilience (the ability of a system to maintain general operational functions under stress). Both node and arrow and geographic cell type network descriptions can be used.

Initial steps:

- What are the nodes in the system and what type of relationships exist between nodes. The relationships aren't confined to being flows or information and can be many different types and strengths of relationships.
- How does a change in any one node affect all the nodes connected to it?
- Describe the structure of the network and calculate several key metrics such as average link density per node and connectivity.

Challenges:

It is very easy and tempting to try to create and analyze a system with too many nodes and relationships. A node and link network that has five or six nodes can easily exhibit complex behaviors that will be too complex to analyze with our initital tools. More complicated and busy models might be just well described with a narrative until you can create network descriptions that are tight enough to test.

Examples:

- A tropical forest food web can be described as a network of strong predatory-prey interactions combined with other much weaker interactions. A species of bird may only have a small effect on a tree species in terms of energy and material flow, but may play a crucial role in dispersal of the seeds, thus contributing to continuing diversity of the forest. A loss of this bird species is inconsequential in the overall biomass but may dramatically reduce the processes that maintain spatial diversity.

- The movement of animals on a landscape can be studied by describing the landscape as a grid of locations that are connected to each other in a 2D network. Connectivity, longest path and biggest patch are network parameters that help understand the issues of fragmentation, reserve size, edge effect, corridors and resiliency.

Figure 3.4 A node and arrow diagram of a food web, showing the predator prey linkages.

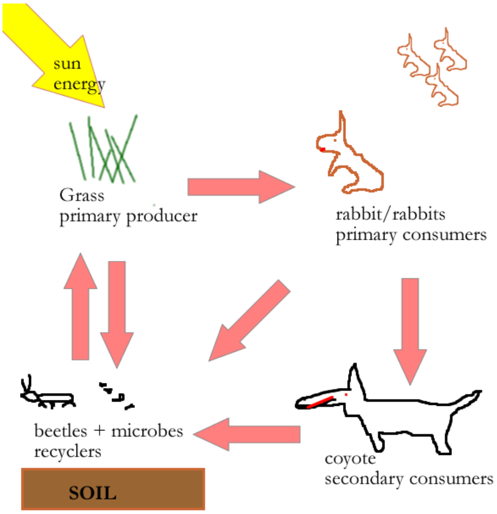
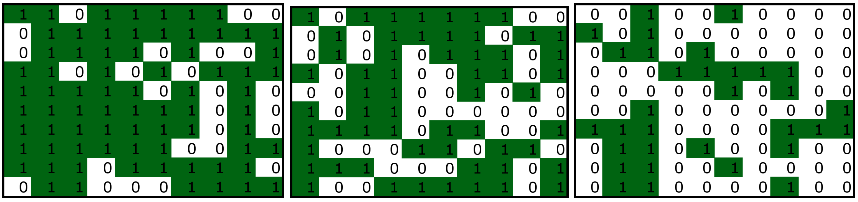


Figure 3.5 A spatial network of connected "cells" that looses connectivity with fragmentation, ranging from a loss of 30%, 41% and 60% of the habitat.



Bounded Rationality, Uncertainty, Indeterminacy and Risk (Chapter 8)

Many environmental decisions entail both risks and uncertainty. Risks can be assessed, calculated and managed. In contrast, uncertainty can't be calculated or estimated well enough to manage directly. Uncertainty can also come from the knowledge gap between what we need to know and what we know.

Initial Steps:

- Conduct an information scan of what we know and don't know.
- Define the limits of what we can know (bounded rationality) and describe how available information is structured.
- Examine the underlying assumptions of risk in this case.
- Build scenarios that center around solutions based on 1) innovation and market, 2) policies, 3) social movements, 4) fatalistic views.

Challenges:

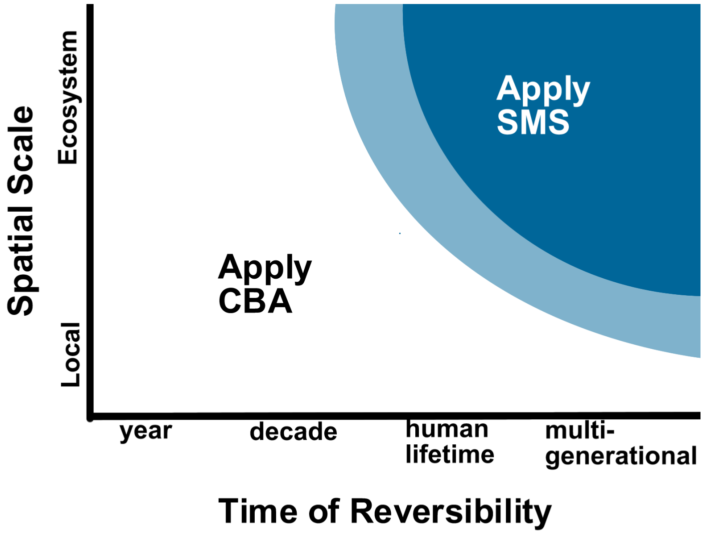
Risk and uncertainty are inter-related and it is not so important at the beginning to have a strict delineation between these. It is more important to understand the underlying assumptions that lead to more technology or energy being applied to move problems elsewhere, in violation of Berry's admonishment to "solve in the pattern".

Examples:

- Global climate change entails some risks that can be estimated and managed and others areas for which the uncertainty is high. For example, we know that damage in coastal zones of developed nations is probably going to increase and there are measures we can take to reduce the potential damage to property and loss of life. However, there is a large degree of uncertainty about what measures may work to decrease CO2 in the atmosphere and we may not actually be able to know without actually implementing these measures (such as large scale forest restoration).

- We'd like to restore a wetland that has been damaged by some human carelessness and invasive species. We don't really know how the wetland will respond to certain treatments so we have the options of conducting a long study (to change these unknowns into quantifiable risks), or to perform some small scale operations (to explore the wetland's response scientifically), or to wipe out the whole wetland and reconstruct a new environment (with a large amount of uncertainty). The choice of approach will depend on the context of each wetland.

Figure 3.6 A decision space for the types of criteria that should be employed if the impact of a project has impact over different time and space scales. If the project has the potential to impact the environment over long time scales, essentially irreversibly, or if the impact will cover an entire ecosystem then the precautionary principle (or Safe Minimum Standard) should be used. If the impact is at shorter time scales or smaller areas, a cost to benefit index could be used.



The next three viewers provide initial steps for decision processes: Games, Environmental Accounting, and Worldviews and Values.

Games (Chapter 9)

A simple way to analyze decisions is to list both your choices and your opponents choices and then determine what will happen with each combination. This approach is called a game matrix and can be extended to understanding your choices when faced with an uncertain environment, or to cooperate or go off on your own for using a shared resource. A strategy is a general approach that you apply to all situations.

Initial steps:

- Identify your choices and your opponents choices.
- Combine all possible choices and catalog the expected outcome for each combination.
- Determine if the game is single-shot or iterated.
- Compare how different strategies might fare.

Challenges:

This simple games matrix approach is so useful and easy to use, the challenge is not to forget that it should be used in combination with other information gathering viewers that would improve the choices.

Examples:

- The "tragedy of the commons" is a game matrix against other people who will benefit from the use of a shared pasture. You can't control when your neighbor grazes but if he grazes too early he might do well but would ruin the pasture for the rest of the summer. If you both cooperate, you will both be able to use the pasture and the net result will be a good outcome for all involved. The tension between what is good for individuals and what is best for the community as a whole can be explored using a game approach.
- The "precautionary principle" is an example of a strategy that you could use in a game against nature in which the exact outcomes are unknown. This principle states that

when given a choice of two possible actions, you should choose the action that leads to the least damaging outcome.

Table 3.1 A games decision square for the classic problem of the "tragedy of the commons". Should you cooperate or graze early on the common pasture?

	Your neighbor - grazes early	Your neighbor - grazes at approved time
You - graze early	You both do poorly.	Best for you. Worst for neighbor
- approved time	Worse for you. Best for your neighbor	Good for both of you

Environmental Accounting (Chapter 10)

Accounting is more than just keeping track of money or inventory. Accounting is the whole process that is put in place to gather information that will allow us to make particular decisions. We can take into account expenditures, revenue, inventory and other assets in many ways. Some of these may help us make better environmental decisions or may signal that something is wrong and trigger more data collection and analysis.

Environmental Economics studies data on costs, revenues, assets in many different forms to study how individuals and states make decisions. We will not address economics in this book. Economics is a higher level of analysis that may use information that was collected by some accounting effort for different purposes and the use of economics requires an understanding of systems, scale and values.

First steps include:

- Determine what to measure that will help make decisions.
- Set up a method to track those parameters, process the data, and interpret it.
- Look for direct use and embedded use
- Examine your system of accounting for "completeness" but not allow for multiple counting of inputs.

Challenges:

Setting up a methodology to collect information in support of decisions introduces strong biases toward making a decision based on what can be measured. You need to keep in mind how will these biases effect the outcomes and ultimate goals of the decisions.

Examples:

- A city could lump all plant related costs (diseased trees, planting new trees, etc) into one budget category. Alternatively, if the city was worried about increased impact of pollution, we could keep track of the amount of time that city arborists have to remove diseased trees so that this information could be pass this information up to the city managers as possible evidence for change in the plant damage.

- The impact of a product, such as diapers, can be determined by a Life Cycle Analysis. This is essentially an accounting for all of the impacts of a using different types of diapers (cloth with home washing, cloth with industrial washing, disposable) and accounting for the impact on trees for paper, cotton growth, water use in growing or washing, other factors. The purpose of accounting is to try to get all the important factors without leaving anything out or double counting, so that consumers can make a decision that fits their particular location. Accounting also helps identify the set of assumptions that are being made in the beginning, such as that in the above example, free-range and un-diapered toddlers are rarely a viable option.

Figure 3. 7 <!—insert modified “hammer” diagram -->

Values and Worldviews (Chapter 11)

Humans make decisions based on their values. According to Cultural Theory (get ref), some sets of values and cognitive skills are self-reinforcing. This results in a few common sets of values that are called worldviews. Different authors that have very similar sets of four categories have suggested several typologies. We will examine how groups who hold each of these would address environmental issues and make decisions that involve technology and risk.

First steps include:

- Identify the diversity of values that are involved in the problem (felt, considered, fundamental and perspectives/tools).
- Put possible framing of the problem and outcomes into the context of the four main worldviews.
- Build possible narrative scenarios or simulation models based on assumptions from different worldviews for comparison.

Challenges:

Including values into scientific approaches is a problematic area. The lack of understanding of how important the full cycle of problem solving depends on social values during definition and implementation leads to criticisms of environmental science being an activist discipline. Using worldviews may help put this on a more objective and pluralistic footing.

Example:

- A person rejects the option of fighting with his neighbor over his legal water rights for growing food and instead moves his family to a nearby valley. Once there he makes a rational choice to farm a small patch of good land rather than a larger patch of overly dry land.
- Different worldviews see issues around global climate change and population growth very differently. We can formulate scenarios for how the future might play out. We

can then choose and work toward general futures by taking action today.

Table 3.2 A set of worldview descriptions that focuses on sustainability.

- Cornucopian
  - optimistic technologist
  - very weak sustainability
  - individual and property rights
- Accommodating - industrial ecology
  - use efficient technologies and market incentives
  - equity for all
  - instrumental value in nature, utilitarianism
  - all capital is interconvertable,
  - weak sustainability
- communalist – committed environmentalist
  - conserve resources
  - green economy
  - collective interests take precedence over individual human interests
  - strong sustainability
- Deep ecology
  - preservationist
  - severely limit resource take
  - broader definition of rights (animal, plant and earth system)
  - very strong sustainability

3.3 Multiple levels within each viewer

The section above describes the major attributes and first simple and directed steps for describing the problem from different views. For example, with the pattern viewer, the first step is to match an observed pattern with a similar looking pattern in the catalog. In the other viewers, there is also a starting set of steps that either have a constrained vocabulary or a diagrammatic representation (or a combination of both). Thus "viewers" are proscribed methods for analysis, i.e. the first steps in identifying how to identify characteristics and take apart the whole problem into these pieces. The set of viewers can also be thought of as a tool box for these approaches. The multiple perspectives framework (described in the next section) shows how these tools can be used together to reassemble a larger picture of the problem.

The pieces of solving a problem using these viewers are:

1. probe the problem for features that fit with different viewers, i.e. use the viewer as a heuristic tool
2. put the problem into a constrained structure provided by each viewer (if it fits in step 1)
3. analyze the problem from the information gathered from each individual viewer
4. synthesize the multiple perspectives gained from the first three steps and determine what information is convergent (shared between multiple views) and which is only gathered by using a particular viewer
5. evaluate the total set of information holistically

The chapters that describe the viewers in more detail contain a description of how each relates to the other viewers. There are particular features that overlap and other features that don't. The list of specific overlaps is provided with each viewer. For example, the Scale viewer focuses on the extent and texture of a particular problem whereas the Systems viewer starts by defining the boundary of the system. The "extent" in the Scale viewer is the same as the "boundary" in the Systems viewer. Some aspects of viewers are very different. For example a flow in a Systems model can be very different than a link in a Network description. A flow in the Systems view can only be the movement per unit time of what was ever in the stock that it came from and goes to. A connection in the Network viewer can be any relationship that may have a positive or negative effect from one node to another. Later we will explore in detail what it means to examine the same system with both a Systems and Network view.

Another feature of each viewer is that it could be extended to more sophisticated analysis. These follow-up analysis features build on or directly complement the initial steps. If you have trouble representing the problem in with the initial steps, it may be a stretch or even inappropriate to continue forcing the problem into applying more sophisticated follow-up analysis. This relates to the common phrase, "When all you have is a hammer, everything looks like a nail." Even if you become an expert in using one of these more sophisticated techniques, you don't want to be locked in to only using that approach. However, the heuristic corollary to this is that if you hit something with a hammer, and it successfully joins to pieces of wood together, then you probably hit a nail.

Table 3.1 Level 1 and Level 2 attributes for each Viewer

Viewer	**Initial steps**	**Follow-up, more sophisticated approaches**
Patterns	catalog, likelihood method	• HBL • Sustainable Health • Alexander's 15 renewable patterns
Systems	constrained icon diagram	• STELLA model
Scale	Stommel diagram	• nested resiliency cycles • time vs. space
Network	diagram, connectivity	• Boolean NK models
Bounded rationality, uncertainty, indeterminacy and risk		weighted matrix models
Games	decision square IPD game against nature	Cooperation Institution building
Accounting	the hammer	

	triple bottom line	
Values and Worldviews	personal choice hierarchy culture theory scenarios	

3.4 Exploratory and analytical use of each viewer

You will be more successful learning to analyze environmental problems if there is an overlap between what you learn from the different approaches. At this most basic level, you can look for how the different approaches provide a coherent central view of the problem with additional features highlighted by the approach. For example, examining a tropical food web might show the overall biomass and diversity of species (with the pattern view), the flow of energy and nutrients (with the systems view) and the multiple levels of interdependence that lead to resilience (with the network view). These views complement each other, have a high level of overlap and converge into a single narrative.

As your analysis becomes more sophisticated however, you will want to emphasize the difference between the views. The different features can't really be called contradictory because they are the result of different forms of analysis, but they can provide multiple, simultaneous realities. Your understanding of the system under study has multiple dimensions and you may not want to try to force these different dimensions to converge or be simultaneously in focus. For example, it might not make sense for you to attempt to directly compare the value of individual organisms to the value of the whole system because some organisms might contribute to the high levels of primary productivity in tropical forests (such as trees and epiphytes) whereas other organisms are important because they maintain biodiversity (such as through seed dispersal). Your understanding of the problem can be developed in related areas that form a mosaic of different views.

The "multiple perspectives framework - MPF described here is the process that starts by scanning multiple perspectives of the problem, chooses a few (at least three) viewers for further analysis, and then brings the different types of information generated back into a working description of the problem. The purpose of the MPF is to guide this process deliberately from the beginning of addressing a problem with the understanding how each new piece fits in. A full description of this framework is given in Chapter 12: Multiple Perspective Framework. Experience working through this framework on a range of problems will make subsequent cycles easier. The point of this framework is to be able to move ahead with actions that could help solve a problem and simultaneously help understand the underlying system more fully or with less uncertainty.

3.5 The value of multiple perspectives

All of the individual disciplines that relate to environmental science are important sources of tools to "drill" down on a problem. The sophisticated methods and theory that these disciplines develop are crucial. However, the authentic environmental issues that we must address are rarely solved by the application of a single disciplinary approach. For example, a very straightforward problem is that there was lead in house paint and this was dangerous for human health. The simple answer is to get the lead out of the paint. After that happened, we are still faced with the problem of what to do with homes that already have lead paint. There are a variety of solutions and, even though we agree it should be done, lack of resources to fix all the homes. Thus the problem morphed from one of detection (chemistry) to local environmental health action (urban studies and health fields).

Multiple perspectives and a diversity of views is crucial for solving problems in innovative ways. One estimate is that 90% of innovation comes from outside the discipline (Innovation Winter 2010 *** find exact reference ***). Page (2007) addresses the value of diversity in solving business problems and comes to the conclusion that "Progress depends as much on our collective differences as it does on our individual IQ scores." In developing his "Diversity Trumps Ability Theorem" he describes value diversity and instrumental diversity:

> "People who have different fundamental preferences might be said to have different *values*. People who have different instrumental preferences but the same fundamental preferences have the same values but different *beliefs about how the world works*. In either case, people disagree over what policy or action to choose, but only in the first case does diversity create a problem. In the latter case, it can prove useful."

Page's point is that it is crucial that we develop teams of people who can work collaboratively on problems in order to innovate and eventually solve these. A diverse group bring together "super-additivity of diverse tools". These diverse groups of approaches don't necessarily have to be hired by a company (Page's focus) but can be assembled *ad hoc* through activist or social groups (Rheingold 2002). Both these authors show that the a big part of the value of collaboration comes from the diversity of inputs and multiple views, not just the agreement to abide by the majority decision. Better decisions come from more active and sophisticated analysis. For example, what many call a "consensus science" approach to global climate change is actually diverse researchers formulating a central model that most agree to and then spending their effort aggressively and rigorously testing the areas of disagreement. Global climate change science has progressed very rapidly because multiple perspectives were brought in and tested.

In order to be part of, or especially to lead, a diverse group that is addressing an environmental problem it is crucial that you see how different viewpoints and methods of analysis bring in different information. The ability to collect information on your own with different methods and then synthesize them into a single narrative is a valuable skill that can be applied to these group situations as well.

PART 2: PRELIMINARY METHODS OF ANALYSIS - "VIEWERS"

Don’t bite off more that you can swallow.

Chapter 4 - Patterns of Interaction

4.1 Definition of "patterns of interaction"

As mentioned in the first chapter, the agricultural philosopher Wendell Berry (1981) says there are three ways to act on a problem: first - don't actually solve it, second - push the problem somewhere else, third - solve the problem "in the pattern". This turns out to be very difficult because the crucial problems that need to be addressed our environment turn out to be those that have ambiguous or hidden patterns. Clear patterns would provide easy-to-follow signals for solutions. What Berry means is that we need to solve the problem in the pattern of its context. The purpose of this chapter is to provide a method for recognizing types of patterns, analyzing them, and scientifically formulating which models are the most likely explanations for those patterns.

The first step in understanding and responding to the environment is actually looking for patterns. Because humans are innately good at seeing useful patterns, we might take this activity for granted. Instead of limiting our abilities to untrained innate skills, we need to develop both a broader awareness of types of patterns and the processes that lead to these patterns. In addition to the usual correlations, distributions, periodic cycles and patterns on different scales, we also need to be aware of patterns that stem from underlying processes that maybe non-linear, complex or emergent.

There are three major categories of patterns; 1) those that form as a result of strong, external driving factors in the environment, 2) those that are the result of multiple, internal interactions, and 3) those that result from both strong external factors and internal interactions. The first category is important and we have many examples of this. We will lump the second and third categories together and focus on those." We need to develop a way to look at these systems with a holistic approach. Complex patterns need to be studied so that we will be aware of them, understand how they work, and be able to take some action that works with these interactions

Sidebar – Important terms for Chapter 4
Pattern of behavior - observed position or trace of objects in the environment
Pattern of interaction - the observed pattern that is generated through from internal objects and processes
Metaphor - metaphor is to use one description from a known area to understand another example
Analogy - specify how examples A and B are alike
Model - a simplified description of a system or set of interactions
Simulation - a model that has user-modifiable parameters, used for understanding the behavior
Visualization - the run of a particular model or simulation without ability to change parameters

Table 4.1 External Drivers and Patterns. With high driving forces there are often internal interactions that dissipate that energy.

External driving force	Pattern
Water flow	River basin erosion
Mixing	Eddies

4.2 - An example of the difference between traditional and complex/interactive views

The following example should help illustrate the difference between the traditional, cause and effect, view and the interactive, complex, view.

Imagine that we have a transparent box that contains some ice and we heat it up with a lamp. The traditional approach to studying this would be to measure the amount of heat in the box and how much energy the box and its contents are absorbing. The heat absorbed by this system would be the independent variable and we could relate the amount of ice and the melting rate of the ice to the effect of heat.

Now imagine a slightly more complex system in which there is a sheet of dark material under the ice. As the ice melts the dark material is exposed. We may get a much more complex, interactive pattern of response in which the heat absorbed depends on the amount of ice and dark material, and temperature depends on the absorption. Given enough effort and measurement, this system could be described by equations and appropriate constants, however we might be more interested in observing and then discovering the "pattern of interactions". In this case the pattern is the result of a positive feedback loop in which the more the ice melts the faster the remaining ice will melt.

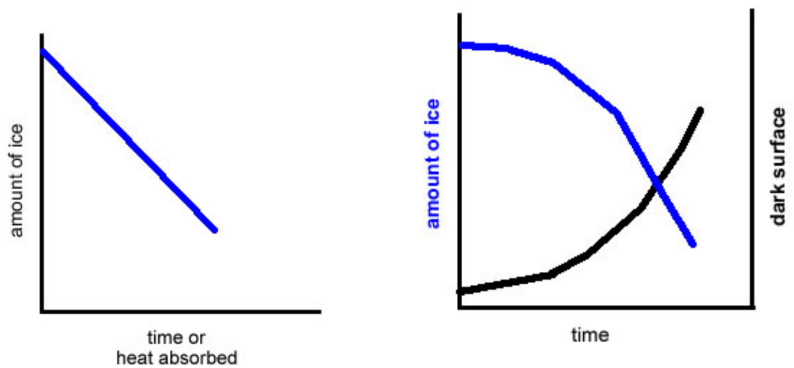


Figure 4-1. Ice melting rates in different configurations. A) ice melts as a result of absorbing heat. The absorption rate of heat is constant and thus the melting rate is linear with time. B) The absorption rate for the system changes as blacker surface is exposed, resulting in an interaction that changes the rate of melting with time. The difference between the two examples is because the second set up results in a positive feedback interaction for heat absorption. In both cases, the amount of heat absorbed directly causes ice to melt.

4.3 Understanding Patterns

Being able to work with patterns requires a complex set of cognitive skills, however we can break these down into three basic areas.

1. awareness/detection - We have to be aware that the environment contains a pattern that might be useful to examine as a pattern of interactions.
2. characterization/description - We need a method for describing and characterizing these models in a more general way so that we can communicate about them and relate patterns that we are observing to ones that have been studied.
3. decision/action - A key piece of understanding is to take action. We should start any action with the thoughtful review of what has been done in other similar situations and what worked and what didn't.

Drawing on a repertoire of patterns

The architect Christopher Alexander has developed an extensive framework for describing patterns in his work on a pattern language *(*Alexander 1964, Alexander 2002).

Appendix 3 provides a catalog of patterns that is organized by the general shape of the response curve or the underlying mechanisms. Studying these examples will help you build a set of metaphors that you can use to detect other complex patterns. In the past, people may have gained a wide range of rich metaphors from their interactions with nature. But since our current society provides most of us with less opportunity for direct, primary experiences in nature, we may have to take time to deliberately study examples of patterns.

Linking patterns to models

Models are simplified descriptions of a system that can be used to characterize, generate hypotheses, and compare predictions. We need models for scientific management. Some models are based on known mechanisms such as a population growth model based on birth and death rates. But models of complex systems are both over-simplified and we often can't prove the actual mechanisms involved. For example, we may observe a population in an ecosystem that fluctuates widely and create a complex simulation of the factors that might lead to those fluctuations. We may not be able to prove (in a traditional sense) that the parameters in our model represent the actual internal structure and factors that lead to the fluctuations. But even with those shortcomings we can use that model to predict changes in the patterns of behaviors if particular management actions are taken. This gap between being able to "show" that the model predicts the basic behavior of a system and being able to "prove" that our model is a faithful representation of the underlying processes is a big sticking point for the use of this approach.

One intellectual tool that is very useful is to look at the likelihood of the models given the observations. This approach turns the standard statistical approach on its side, and compares several models to see which is more likely or what is the degree of likelihood of any model given a set of data or observations. In contrast, traditional statistics can be used to tell you how close the data fit to a given model or equation. For starters we can use likelihood approach by generating several complex simulations that might fit the observed pattern and then estimating which model is most likely given the data we have. We could follow that up with more sophisticated analysis, such as Bayesian methods for pattern matching.

Another good use of these simulation models is to use several of them to generate predictions that are either ambiguous or conflicting. A simple example of this is to use exponential and sigmoidal models for the growth of the population (Figure X) and to predict at what point the predictions diverge by more than 10%. Then we can use; 1) isolated experiments, 2) specifically crafted

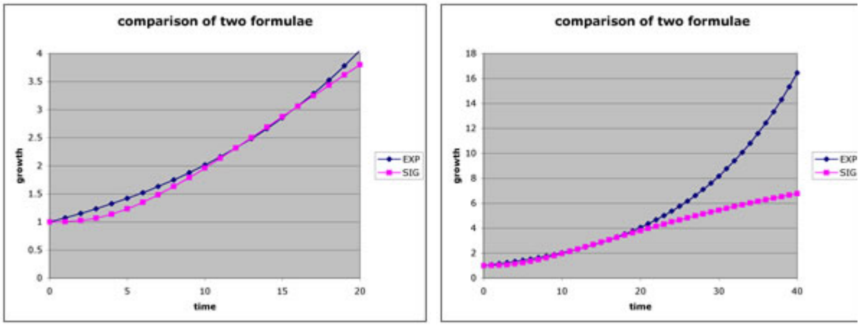


Figure 4-2. Comparison of two growth models. Both figures have the same underlying equations generating the curves, the only difference is that one "simulation" runs twice as long. In the figure on the left, both curves are incredibly close, within the size of the symbols for many points. Only after the simulation runs for another 20 days is the pattern clear that the exponential equation continues to grow explosively and the sigmoidal curve levels off.

intentionally disturbances of the environment, 3) management actions, or 4) wait around for natural perturbations to test the model predictions. It is important to elaborate on the differences between these four choices for testing the model. Traditional science would employ isolated and controlled experiments. This allows the investigator to control the conditions and use a matrix of changes in the independent variables. This approach is very effective and powerful and has been the basis for huge advances in environmental sciences in agriculture, limnology, and other areas. Often it is not possible to run isolated and controlled experiments and science has to rely on studying a single, non-replicable event. For example, the modification of unique lakes to see what might happen is sometimes possible. More often however, the only modifications that can be made for an ecosystem is through management action. It is not feasible, affordable or ethical to simply perturb a lake to see what happens. Instead, there are management objectives that can be addressed and studying that action with before, during and after measurements can be extremely valuable. The final option is to observe the changes in natural system due to natural perturbations. The problem with this is that you never quite know when a natural perturbation (such as a fire, drought, flood, pest outbreak, etc) will happen. You may also not have sufficient pre-perturbation data or you may not be able to mobilize monitoring support and equipment in time during a perturbation. For example, monitoring plans are designed to be cost-effective and routine, not to wait around for perturbations. I know of an example where people involved in highly organized monitoring plan had real difficulty justifying the change in their work schedules to their superiors when there was a exciting breach of a levee that led to an unexpected surprise event in their lake. The most promising of all of these approaches for dealing with ecosystem level changes is the use of scientific adaptive management.

Taking action

When we say that there is a "problem" in the environment, we are describing the situation in judgmental terms. It is the same as saying that the pattern of interactions between all the actors and objects does not completely match with what we think **should** be happening. We would **rather** see a pattern that aligns with our values and provides the best outcome for us as humans. Problems are a mismatch of values and existing patterns. All of our observations include this type of value judgments. It is important to incorporate our values (as scientists, managers and citizens) into this process and not to try to exclude values by separating these from facts. There are on-going philosophical debates over the separation of values and facts and the situations when a more objective or subjective approach can be used. The simple reason to acknowledge and deal with values right up front as part of the environmental science process is that those of us who are studying these systems have the richest and most intimate knowledge of that environment. We shouldn't pass the responsibility for subjective decisions to those people whose experience with the system is second-hand or virtual. Even the most technologically sophisticated and intense projects rely on first hand observations to detect when something is not right. "Houston, we have a problem."

Remember that the process of observing a system and trying to describe it with a set of likely models is not the same as proving that something wrong is happening. We may be looking to detect the first inkling of a problem. In many of the studies on ecosystem degradation, the first indicator is a slight change in pattern of interaction. The potential shift from one ecosystem structure to another happens when the resilience has been exceeded and some threshold crossed. Slight changes in the response may be the most promising approach we have to predicting and managing these systems.

Scientific adaptive management as described by Norton (2005) has two required objectives; 1) to use management efforts to improve the system being managed and 2) decrease the uncertainty for future management actions. This is more constraining that it might seem since both of these are required. There are often actions taken to improve an ecosystem that are not done in a way that will help better understand the system for the future. Many of the environmental problems that we need to address are complex in both technical and social dimensions and may qualify as wicked problems in which any change in the natural arena will result in simultaneous changes in peoples' values. In these cases, scientific adaptive management approaches are the only workable alternatives for scientists but there maybe other avenues open for public or business activities (see Chapter 14).

4.4 Some patterns are cryptic

Clear patterns in environmental factors allow us to understand the underlying processes and guide our technological applications and policy decisions. For example, increasing pollution in a stream over several years or the appearance of an invasive weed in a native grassland are clear signals that something is wrong. Some of the most important problems that we face, however, aren't marked by clear signals. In fact, ambiguous or cryptic patterns may be the reason why these problems are persistent and difficult to address. This principle is similar to one familiar to aquatic ecologists, if you can measure the nutrient in the water easily, that nutrient is probably not of interest. In this case, if you can identify the factors in an environmental problem easily, it's probably not a very serious problem. A corollary to this statement is that if you think you can describe and solve a serious environmental problem in terms of a single set of factors, you are probably mistaken. The most challenging problems that we face are both complex and have poor alignment between actors' values and the benefits from alternative solutions. These are classified as "wicked problems" in which neither more scientific information or public awareness will be sufficient to address the problem (see Chapter 1).

One example of a crucial process that is difficult to detect at early stages is runaway positive feedback (Figure 4-2). At low values the incremental growth is small, but as the value increases so does the increment in any time and can eventually lead to an explosive growth in the system. In the early stages the positive feedback nature can be hidden in the variability in the data or by overlapping cycles. Global warming is a good example of this type of process. If this is a positive feedback process (such as might be caused by increasing temperature releasing more CO2 from tropical soils or methane from the tundra), it will be much easier and cheaper to take preventative steps now than repairing the damage that is done later. The issue is that we (as environmental scientists) don't know if this is a simple increase or a vicious downward spiral with a threshold.

Biodiversity loss is another crucial issue facing us. Currently is it generally accepted that most processes are linear, a 1% increase in the causative factor will have a proportional change in the output function. However, biodiversity loss may be highly non-linear. There may be a threshold in our level of human disturbance that leads to a rapid and dramatic restructuring of ecosystems and communities to be much more impoverished. Complex models for this type of shift have been constructed that show their maybe crucial levels of fragmentation that happen at some threshold. These processes are discussed more in Chapter 7:Networks. The scientific burden is how to detect the threshold before we cross it, especially if it is a non-linear response. We may never be able to recover what we lost. One of the favorite metaphors for biodiversity loss, is that we are going to remove some random rivets in your airplane. How many rivets can we remove with no effect and how few would we have to remove after that to have a catastrophic failure of the plane. Although very physical/mechanical, this metaphor illustrates the potential to be near failure without crossing, but that when just one more insult is added to the system there can be a catastrophe.

4.5 Formally describing patterns

We will explore three ways to describe general patterns in the environment: 1) catalog, 2) generative grammar, and 3) simulations. The first is to make a big list of all the categories of patterns with examples. Any environmental observations can be matched to this list to determine which patterns might be in play. This catalog should help define the differences in behavior between patterns and help the users to consider a broader range of patterns. The use of this list is algorithmic; collect observations, compare the pattern in the observation to the list, and make a selection. The second approach is to develop descriptions of these patterns as a special language that either uses a constrained vocabulary (of narrowly defined words) or an extensible vocabulary (that can be user modified). The generative vocabulary approach is completely open-ended but can take a lot of effort to set up in the first place. The third is to use simulations of complex interactions to generate patterns and then attempt to link those patterns back to the processes represented by the simulations. This could be very time consuming because an individual simulation has to be found that can produce a version of each of the patterns.

4.6 Find the pattern in an extensive catalog

The first suggested approach is to compile and study a list of patterns that might be observed in environmental data. Example images or identifying characteristics for each category of pattern are given and, in some cases, critical elements that differentiate this pattern from others. This big list is useful when scanning a broad range of possible mechanisms but can't be used as a method for proving that one particular underlying mechanism is the cause of an observed pattern.

You might use a search process such as the following on the big list of patterns:

- What do you suspect are important parameters? Look at patterns in the list that might be related to those parameters. For example, if you think that the diffusion or mixing might be important, there are several patterns that are characteristic of those processes.
- Are there multiple processes that range in physical or temporal scale? There are several sets of patterns dealing with hysteresis or thresholds that you might want to consider first.
- Are there patterns in smaller or short parts of the system that might be indicative? For example there might be a hint of a diffusion pattern or fractal pattern in just a small part of the overall pattern that will help you identify some of the processes.

Remember this isn't a valid search strategy for proving any relationship, rather a starting point for looking for complex mechanisms that may generate the pattern you are observing. Also, this is not valid because no criteria for matching have been established, i.e. there is no stopping rule for when your search would be complete.

It is better to consider this list as a checklist of patterns that should be considered. Although most of us are able to easily identify linear correlations, cyclic patterns and understand the importance of variability, it takes different skills to identify the other patterns. These skills are probably best developed by working through the concrete examples that will be provided in the case studies, rather than from study of the underlying mathematical and theoretical formulations.

This catalog is divided into eleven classes of patterns ranging from simple to complex to multiple-complex systems (Table 1 and

Appendix 3). The purpose of this categorization is to facilitate learning and teaching. A particular category should share a general metaphor that contains the salient features of the system. For example, "swarm" patterns are all related to a group of bees or ant colony. There are simulations and analysis tools that are appropriate for understanding and describing these patterns.

Table 1. The catalog contains the following patterns that can be related to their dominant metaphor. Please see Appendix 3 and online for images of these classes (and sub-classes).

Pattern class	**short description**	**general metaphor/ characteristic example**
1. Regular and geometric patterns	can be described by simple algebraic relationships in 2 or 3 dimensions	sphere that results from surface area to volume relationships linear correlation between cause and effect
2. Dynamic systems	description of a process over time that obeys simple relationships at any instant	exponential, positive feedback systems "logistic" growth model
3. Fractal shapes	geometric shapes that have constant ratios between the components	tree branching coast line
4. Fractal frequencies	temporal or distribution patterns that when analyzed for which a change in	Zipf's law for city size word use frequency

	rank results in the same ratio of change in the frequency	earth quake frequency and intensity
5. 2D mosaic	any spatial pattern that has patchiness between several to many components	forest fire patches patchiness of housing and farms fragmentation of landscape that leads to biodiversity loss
6. Pulsing	temporal pattern that switches between resource accumulation and resource exploitation	predator prey interaction "bubble" of the exploitation of a non-renewable mineral resource
7. Turbulence and self-organized dissipative structures	energy dissipation through eddies	eddies in a stream switch from laminar to turbulent flow when increasing the flow out of a faucet
8. Flow and stress	patterns that result from low energy solutions to dynamic processes of flow or stress from placement	hexagonal packing flow of water around a rocks or of tree growth around a branch
9. Bistable/threshold with hysteresis	processes that have a distinct threshold from changing from one state to another	lake with marsh and open water islands of hummocks of grass in a xeric

	(sigmoidal instead of linear) and with the characteristic that it is more difficult to change the current state away from that threshold (bistable)	environment
10. Swarm	individual agents each following very simple rules leads complex emergent behavior of the group	insect or bird flock percolation of an innovation or disease in a society

4.7 Use a generative grammar that will be able to describe all environmental patterns

Although having a "check list" of patterns seems tidy and well defined, the world is often messy and ill defined. Ill-defined in the sense that new observations may fit into multiple categories and could be modeled equally well with different approaches. For example, the loss of biodiversity due to habitat destruction can be modeled using linear systems dynamics that demonstrates an equilibrium between loss and immigration, or it can be modeled using cellular automata that approximate habitat fragmentation (Bak 1996). Both modeling approaches are based on justifiable mechanisms and describe key features of the behavior. There are slight differences in the predicted threshold for maximum decline in biodiversity that makes this comparison interesting. But the point here is that there is not just one way to describe the behavior of the real system.

The challenge we face, as environmental scientists, is how to describe patterns within our discipline and for others outside the discipline. This is a general problem faced by many groups, do you use a constrained vocabulary that operates within a defined set of categories, or do you use an extensible vocabulary that can be applied to new patterns as we discover and study them? The extensible vocabulary approach is more powerful within the discipline but the categories may be simpler and more understandable by those outside the discipline, for example for policy or educational purposes. We need to have and use both approaches. In particular, as the adaptable vocabulary identifies important patterns more specifically, we need to include these new terms into the constrained vocabulary/categories. Later we will discuss simulations that can be used to visualize the pattern and dynamics of interaction.

This discussion of a language of patterns relies heavily on the work of Alexander (1979) and Alexander et al. (1977). Although his focus was architecture, the importance and process of building a language to describe patterns should be the same. Alexander defines a "pattern" as a rule between a context, the system of forces in this context and a configuration that allows these forces to resolve themselves. Each pattern includes the elements of "context", "system of forces" and "configuration". The purpose of the pattern language is to precisely describe patterns, give them a name and share this new word in the language with others. Alexander makes the point that "the expertise is in the language". Thus to develop and share this expertise, we need to develop and share a language.

A simple example of a description of the pattern would be:

context	**system of forces**	**configuration/pattern**
surface water flow on terrain	• gravity and terrain steepness • water energy • soil erosion • transport of eroded particles	gullies are formed at edge before the steepest gradient of the slope

This pattern could be named "soil erosion and gully formation". What is interesting about this pattern is that as gullies are formed, that causes a new steep edge to be created and further gullies leading into that gully. It has a fractal characteristic. This could lead us to create a new pattern that has to do with how these gullies are arranged on a larger scale.

context	**system of forces**	**configuration/pattern**
drainage basin made up erodable material	• gully's are formed • new gullies create steep leading edges	small gully's form on the edges of larger gully's, at all scales

We could call this pattern "fractal drainage basin" and this pattern depends on the system of forces that causes the gullies. Likewise "gully formation" must be part of a larger context that collects and causes water to flow from a source. Alexander (1979) describes how each pattern is part of the pattern of a larger context. Each pattern is dependent on the context and the context is reciprocal dependent on the component patterns.

These two example patterns above illustrate the grammar, or structure of these relationships. Each identified pattern has the three elements; context, forces and the outcome. The context may include other patterns, resulting in nested sets of patterns. There is no reason to constrain a pattern to only exist in one context, and thus these sets of context and sub-patterns are not strictly hierarchical.

If a language of patterns were developed for environmental observations, it would improve communication and shared expertise. However, even for your individual use, describing all patterns with the same set of elements and making explicit relationships between contextual and sub-patterns should be very useful.

Table 2: Four further examples of patterns that contain all three elements. There can be one or more forces that are resolved through this pattern. These examples are given in a markup language style to show how they could be presented uniformly.

```
<pattern>
     <name>LD50</name>
     <context>range of toxic concentrations
     in water</context>
     <force>toxic strength of
     compound</force>
     <force>variability in
     individuals</force>
     <force>bell shaped distribution of
     variability</force>
     <configuration>cumulative toxicity is
     predicted by the concentration with 50%
     of the organisms dying at or below the
     concentration called the
     "LD50"</configuration>
</pattern>


<pattern>
     <name>intraspecific genetic
     variability</name>
     <context>natural selection acting on a
     population</context>
     <force>variable reproductive potential
     due to a condition or resource </force>
     <force>limited population size</force>
     <force>genetic processes that lead to
     variable genetic makeup of progeny in
     any generation</force>
     <configuration>a crucial environmental
     factor leads to higher relative
```

```
      reproductive rates for some
      phenotypes/genotypes within a
      population of fixed
      size</configuration>
</pattern>

<pattern>
      <name>resource limitation</name>
      <context>population growth that
      depletes a particular
      resource</context>
      <force>intrinsic growth rate
      potential</force>
      <force>growth of organisms sequesters
      resource into unusable form </force>
      <force>actual growth rate depends on
      available resource
      concentration</force>
      <configuration>increased numbers of
      organisms decreases available resource
      which results in decreased growth rates
      as the population size is higher, the
      logistic growth model is one instance
      of this</configuration>
</pattern>

<pattern>
      <name>demographic transition</name>
      <context>population growth in
      countries</context>
      <force>birth rate </force>
      <force>death rate </force>
      <force>increase health services</force>
      <force>industrialization</force>
```

```
     <configuration>In a very simple view,
     the demographic transition is a set of
     steps that countries go through with a
     decrease in mortality through better
     health care followed by a decrease in
     birth rate that is related to (but not
     cause directly by)
     industrialization</configuration>
</pattern>
```

4.8 Using simulations to generate patterns

Wolfram (2002) has described a "New Kind of Science" in which he uses rule-based cellular automata to generate very complex patterns and then analyzes these patterns for where the complexity comes from. Using a simple rule set for each cell, a method for calculating a new row of cells with each time step, and a starting "seed" row; you can iteratively generate new rows until a pattern emerges. The pattern comes from the simultaneous interaction of the current row of cells with the rule set to give a changed pattern in the next row. You might be familiar with this type of cellular automata in the game of Life or have seen a grid-based version of this in models of forest fires.

insert example rules and image from Wolfram

insert ILP with pictures

4.9 Two examples of employing patterns to address an environmental problem

Pollution levels in a stream

An example of simple cause and effect type relationship is the amount of pollution that is introduced into a stream by a point source. We're going to examine this with two modes of learning, mostly inductive and mostly deductive. This example will be compared to a complex problem.

Inductive approach- starting with observations

You measure the pollution put out by the point source (such as a single sewer outlet) and get the following data in Table 3:

Table 4-3: Example data from a stream-monitoring project.

date	**point source g per hour**	**stream g per liter**
1/15	3	0.030
2/15	5	0.033
3/15	7	0.035
4/15	6	0.040
5/15	7	0.070
6/15	6	0.080
7/15	4	0.080
8/15	5	0.200

Plotting this data you get a bunch of points as shown in figure 4-3.

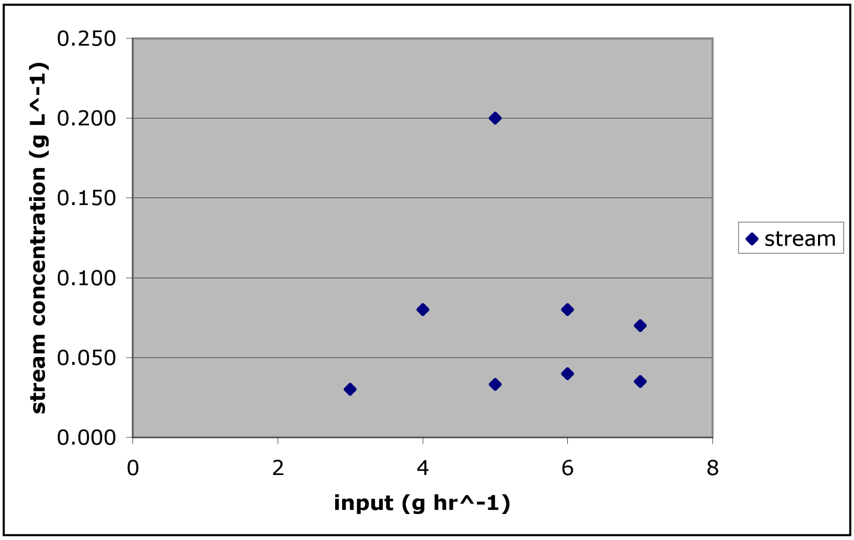


Figure 4-3. Data from Table 3 plotted as the stream concentration related to pollution input rate.

After seeing this you think about it and realize that you need to know the volume of the stream flow at any time to calculate the resulting concentration. You retrieve that data from a gauging station and add it to the table (Table 4):

Table 4-4: Recalculated data from Table 3 that includes stream flow rate.

date	**stream flow L ^hr-1**	**concentration of pollutant g/liter**	**mass of pollution transported by the stream flow * stream conc.**
1/15	100	0.030	3
2/15	150	0.033	5
3/15	200	0.035	7

4/15	150	0.040	6
5/15	100	0.070	7
6/15	75	0.080	6
7/15	50	0.080	4
8/15	25	0.200	5

Thus the highs and lows in stream flow change the stream concentration independently of the point source input. Multiplying the stream flow by the concentration in the stream will give the mass of pollutant that has been put into that total volume of water. This calculation (column 2 * column 3 = column 4) compared to the data column 2 in Table 4.3 confirms that you have accounted for all of the pollutant.

Deductive approach - starting with the laws

In class you are given the law of conservation of mass and told that this should apply to mixing problems such as pollution input to a river. You consider this law and come up with the following hypothesis: The total mass of pollutant in the river will always be the same, but the concentration might increase of decrease depending on the relative amount of dilution from the flow of the river. Following this approach, you measure the mass of pollutant, the flow rate and predict the concentration of pollutant that will be measured downstream.

What is the difference between the inductive and deductive?

In the traditional scientific approach that focuses more on deterministic processes, there is a gap between concepts and the application of this knowledge with scientific tools. For example, how do you know that the total mass of pollutants in the stream is conserved? However, most of the analytical tools used in the traditional context are based on deductive approaches and the power that comes from that generality.

Instead of having to jump to this assumption (that the general approach will apply), investigators using the more inductive approach wade through the swamp of rich, personal exposure to some complex systems. From this experience and simulations they realize that only some of the features of the system can be captured. Collection of information can be guided by experience and from simulations but shouldn't be constrained by the presupposing certain relationships. The data from a more inductive approach can be analyzed with appropriate tools that search for patterns. These inferential tools can be applied to simulation output for the student to gain experience at detecting and rejecting patterns.

Both approaches have a gap. In the deductive approach, invoking the laws of science early presents a gap between what the investigator actually sees and experiences and the process of collecting measurements. By crossing this gap early, powerful measurement and analysis tools are readily available. In the inductive approach, the investigator must collect data and form it into information without the efficient constraints of laws, and then cross a gap when attempting to apply inferential statistics of similar tools to help decide between possible patterns in the data.

Example 2: Sand pile model for landslides

The previous example illustrated how some problems could be addressed with either deductive of inductive approaches. This example will show that even though simple governing rules can lead to complex behavior the investigation of a phenomenon might have to work backwards from inductive, experiential start. Simulations of the system demonstrate how the behavior can be different each time, but that there are generalizations about the pattern of behavior that can be made. These complex systems have simple rules but multiple possible outcomes, i.e. they aren't deterministic.

Dropping sand grains one at a time onto a pile is one example of the complex behavior that can arise from a very simple set of rules. The rules are that:

- sand grains are added one at a time
- if, anywhere on the sand pile, there are two grains right on top of each other, there is a good chance that this pile of grains will fall over.

Below is a sketch a few steps in the building of a sand pile. There are simulations of this process available on the internet.

1. pile of sand develops

2. new grain added to top

3. grain could fall either direction

4. it happens to fall to the right

5. and then further tumbles

6. and finally ends up

At step 3 it could have fallen to the left, causing a bigger avalanche.

3. it could fall either way

4 - alternate. it falls to the LEFT

5 - alternate. causing a larger cascade

In one case one grain of sand tumbled down the pile, and in the other case it caused a larger event.

In a sand pile buildup there are lots of little tumbles, more small avalanches and only a few large avalanches. This is because if there hasn't been an avalanche for a while the pile gets steeper and steeper until it causes a large event. This model and the explanation have been explored in great deal in other sources (for example Bak 1996).

For the purposes of this example, we are interested in the frequency of the events and how big they are. It turns out from many observations that avalanches that are about twice as big are half as frequent. If you plot the frequency of events (Y axis) vs. the size of the event (X axis) you would get a plot that looks like this:

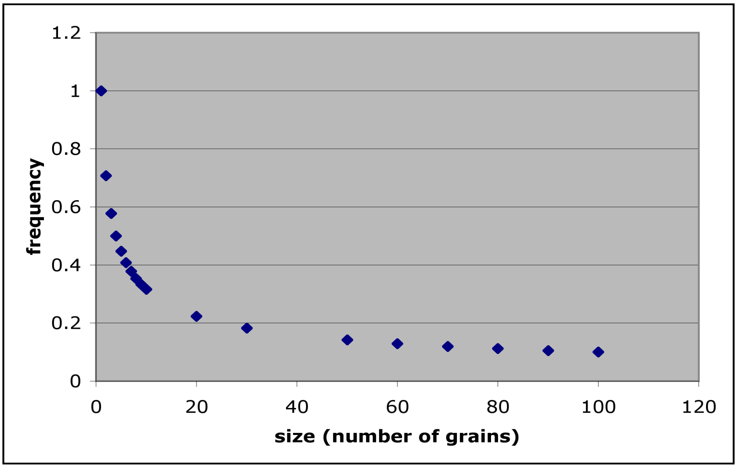


Figure 4-4. Frequency of landslide as a function of the magnitude of the landslide. There are very few large events, but many small events.

If you use a log-log plot, by simply making each axis a log scale, it looks like this:

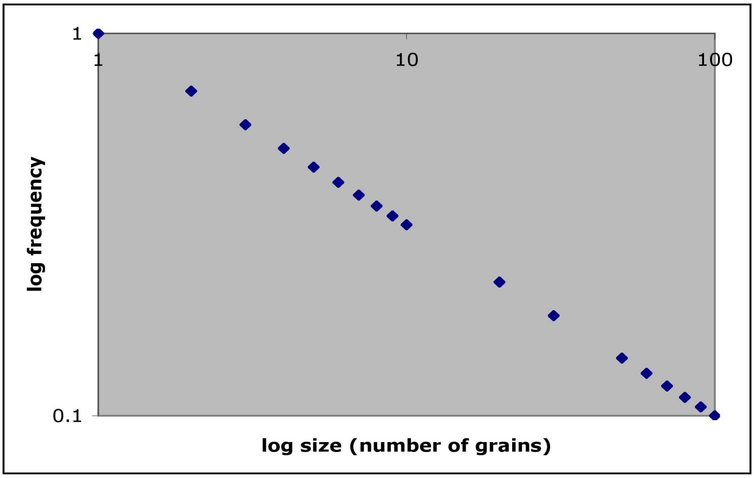


Figure 4-5. The same data as in Figure 4-4 plotted on a transformed set of axis: log of frequency vs. log of the size of the landslide.

The log-log transformation (Figure 4-5) works because we are dealing with constant ratios of change; if the size increases by a certain ratio, then the frequency decreases by a related fraction. It doesn't matter where you are on the graph, whether you are at the second, or 82nd most frequent event, the ratios hold. This is an example of a scale independent relationship. Other examples of this pattern of behavior can be seen in landslides, earthquakes (Gutenberg Richter Law), and the size of cities (Zipf's Law).

4.10 Likelihood of mechanisms given a pattern

This describes a method to establish the likelihood that an observed pattern is similar to one that has been described in the catalog, with the implication that we might understand which processes formed it. This does not prove that the observed pattern was caused by a particular mechanism. The steps are: 1) observe a pattern, 2) look for likely patterns in the catalog that are candidates for explaining the observed pattern, 3) analyze the candidate models to see which is more likely.

For example, a stream drainage basin may look like Figure 4-8.

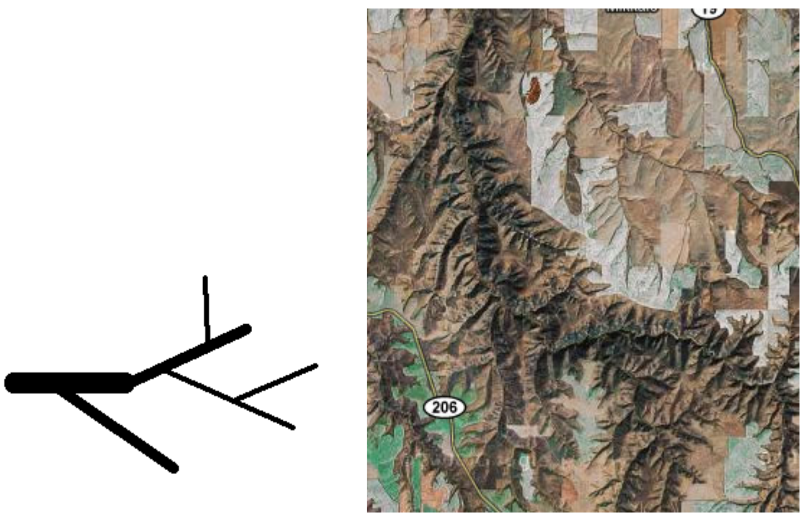


Figure 4-8. The pattern of a stream basin with several small tributaries. The image at the right is a Google Maps image of one of the upper stems of the John Day River in Oregon (Copy right by Terrametrics 2010 and Map data Google 2010)

Looking at the catalog of patterns (Appendix 3) there are several patterns that are similar to this one. Picking several as candidates to explain this pattern:

> Pattern 1.1 - This is bigger pattern is just a combination of straight lines, implying that the main forces causing this pattern are just those that cause water to flow down hill in the shortest path.
>
> Pattern 3.4 - A fractal stream basin, implying that historical erosion pattern has lead to the one main stream and the tributaries.
>
> Pattern 3.6 - A biological fractal, such as the lines on the bottom of a sand dollar.

The representation of our observation is important in the analysis. If we were to look at the stream on a road map, we might see that the stream width was not accurately represented and the stream might be very similar to a set of connected straight lines such as shown in figure 4-9.

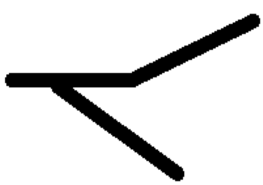


Figure 4-9. (a) Steam basin pattern as it might look on a road map with stream sizes all the same and smaller ones dropped off. (b) The bottom of a sand dollar (pattern 3.6).

Given that we know it's a stream pattern, pattern class 3.4 makes sense and the images in the catalog are very similar. However, just by looks, pattern class 3.6 looks most like our pattern. So unless we had some other information about how these were formed we might have to conclude that our observed stream was more likely to be similar to the fractal patterns (3.4 or 3.6) than a straight line (pattern 1.1). We would probably need to add more detailed observation and representation of the streams to differentiate (based just on the pattern) between pattern 3.4 and 3.6.

In this approach we are looking for likelihood not "truth" or a "provable" mechanism. This makes an important link to the concept of the "precautionary principle" in which we are looking for likely problems that might crop up and cause trouble or damage, and we are willing to suffer some false positives to get a better chance in including those mechanisms in the mix. The same holds here, we are looking for models that may describe the observed data and we would much rather include a candidate model (because we can deal with it) than we are trying to eliminate models. Each subsequent round of study should help us discriminate between the likelihood of the models.

4.11 Learning from and communicating about patterns

Metaphors, similes and analogies

These definitions are from Rigney (2001).

> "Metaphor is a mode of thought wherein we interpret one domain of experience through the language of another."
>
> "Simile is more literal than metaphor, asserting not that A is B, but only that A is like B in certain implied respects."
>
> "Analogy goes one step beyond simile, specifying ways in which A and B are alike. We develop an analogy when we begin to explicate the points of resemblance that metaphor and simile only hint at."

Metaphors are very useful if the audience has some other domain of knowledge that can be called upon to jumpstart their understanding. If the audience is aware of features that define the metaphorical system and can use those features as cues in a new domain. For example, you could use an agricultural metaphor to describe biodiversity to farmers or you could use an economic metaphor to talk to financial group. It might not be as productive to talk to financial people using a farm practice metaphor, they might not get the connection. It's only a good metaphor in the context of the receiving group. In the process of learning about complex systems, such as networks of research faculty, the metaphors that we are using are primarily from biological systems that the reader would associate with complex networks, even though they don't really understand how complex networks function. Thus to link a thought to ants, food webs, spatial neighborhoods of farmers, and others, is limited to the metaphor. After the basic comparisons are made, we can't rely on gaining any more understanding of the system by pushing the metaphor further.

We often use machine metaphors to describe how living systems work. For example, the heart is like a pump. If you know how pumps work (with flow, stroke volumes, back pressure, valves, etc.) this can be a useful start. Not surprisingly these can be oversimplifications. For example, using a thermostat metaphor to describe how humans regulate their temperature (too hot, turn on cooling) is deceptively simple. Humans cool using at least 5 mechanisms with overlapping time scales (skin flushing, blood flow, sweating, ventilation, behavior). All together these overlapping rate scales (some faster and some slower) provide a highly resilient control mechanism for keeping our bodies within a workable range of temperature. It is fashionable to use living system metaphors to describe industry, such as an eco-industrial park or survival of the fittest. These metaphors can be misleading and, in fact, very dangerous unless you really understand the underlying system (ecosystem or evolution) and know the legitimate boundaries of the metaphor.

We acquire metaphors through an exposure to a range of systems that generate patterns. This will help us recognize patterns as being the result of some processes that we are familiar with. The pattern may be the process in action (oscillation of a pendulum) or it may be the trace left by a process (debris line at high tide mark). There are probably many shapes and patterns that you might have seen but didn't realize the complex mechanisms that caused them. Here are some examples:

Table 4.5 Common patterns and the mechanism of formation.

offset of plant stems	
spiral in a sunflower seed	
streams in a drainage basin	
distribution of airport hubs across the US	
patches of weeds in your yard	
irruption of caterpillars	
water changing from smooth to turbulent flow as you increase the flow out of the faucet	
the grain of wood around a knot	
clumps of grass in a marsh and little ponds in the marsh	
the way flies dance around each other in a shaft of light	

Use of metaphors in environmental science

There are many required skills to work in environmental science and policy. Some of these are obvious such as understanding how science really works and to be able to perform the technical aspects of scientific monitoring and experiments. Additionally you need to be able to deal with uncertainty, be able to communicate with a range of audiences, and to help design monitoring and research schemes. In order to be a leader, you have to know where you are going and how to get people to consider your view. A powerful way to do that is to use appropriate and favorable metaphors to frame the conversation. You also need to be able to recognize when other people are using non-favorable metaphors to frame the discussion. This may seem manipulative or unethical, but if you do this openly and identify the different sets of assumptions that are implied by alternative metaphors, it can lead to a more productive and transparent discourse. Table 4-6 shows a comparison of simple mechanistic metaphors vs. not-so-simple ecological metaphors.

Table 4-6. Mechanistic vs. Ecological metaphors.

simple (mechanistic)	**not-so-simple (ecological)**
ecosystem as a homogeneous area	spatial and temporal connectivity
competition	cooperation
stability	resilience
natural selection through survival of the fittest	importance of maintaining biodiversity in evolution
competitive exclusion	survival
equilibrium	pulsing
steady-state	dynamic
global homogeneity	heterogeneity

Learning from the landscape

We learn from the patterns in the landscape. Some of these patterns are natural, some are human, and increasingly some are a combination of both. Our environment provides a constant stream of information that we can use. Previously, this information flow was crucial for survival, competition and cooperation. For example, it was very valuable to be able to estimate when it would rain, where you could find a tree with fruit on it, or how you might be able to get from one place to another. More recently, it seems that many people feel that we are independent, or at least not dependent on nature on the every day scale. We seem to feel that we don't need the information from our environment. Whether or not this is true is debatable, but the fact that we are debating our ability to be independent of environmental information (both the human and natural environment) is an important indicator of how our current society perceives the dependency. One of the central arguments in sustainability is whether the natural world is irreplaceable (so called "strong sustainability) or whether other capital (human, constructed, or other) can replace natural capital ("weak sustainability").

I'm going to step away from the argument of whether we should be more attuned to our natural environment to address the issue of what we information we gather from our surroundings on a daily basis and what we have learned from the landscapes in which we have lived. It would seem inarguable that human abilities to sense and process environmental information would have been very valuable. We have innate capacities for dealing with some types of information better than others (see above). How can we use these capacities to help us understand and correct environmental damage? What mental limitations do we have to learn to overcome? Although these are open-ended and possibly unanswerable questions, there are some simple activities that we can participate in that will help us be more tuned into the environment. Here are several examples.

- Take a walk in the woods and just let yourself believe that there is a pack of urban coyotes that might attack you. This will heighten your senses and be an entirely different awareness of small noises going on in the brush.
- Look at photographs of your local neighborhood from the past. Some things have changed dramatically and others are the same. Similarly, visit your childhood neighborhood and find the little parks or trees that you used to play in. If the current state of these places is degraded it may actually make you sad for the loss.
- Go some place familiar but walk at half speed. The shift in attention to small changes in the environment will probably surprise you.
- Take your dog for a walk and follow where he wants to go. Dogs and other animals live in a totally different perceptual environment than we do that includes the history of any dog who passed that bush recently and sounds coming from all sorts of places. You can also do this same exercise (with different results) with a small child or a horse.
- Look at Google Map and drill down to your neighborhood level. Notice features that are off the road that you can't see in your neighbors' backyards and in nearby businesses or parks. Look for a change in scale of patterns as you go from your house and street up to the citywide view.

There are more activities like these listed in Appendix 2: Etudes for Observing the Environment.

4.12 CASE STUDY: The patterns in the landscape can indicate different natural and social processes

to be added later and will include

- catalog of patterns

- description of processes that can lead to these patterns
- satellite images in your location

Chapter 5 – Stock and Flow Systems

5.1 Definition of the “systems” approach

We are going to use a specific definition of how to think of a problem as a system. This isn't the only definition of a "system" and might be different than the one (or ones) that you are familiar with. The purpose of our limited definition is to provide a short list of characteristics of a system and then try to describe many different structures and behaviors using just this short list. This intellectual process both helps simplify what we need to know to start looking at problems and will help us see similarities between different systems.

Because this "systems" approach is useful for simplifying problems, looking for significant processes and identifying controls, it is a good way to generate environmental information. But the systems approach can also be used to create simulations of future conditions and to communicate these to other people who are making decisions. One of the benefits of this approach is that it clearly identifies the assumptions on which simulations are based. A good "systems" model is both a valuable research tool and a platform for communication and decision-making.

A "system" is any set of connected processes and quantities of resources. It can be as larger or as small as you want to set the boundaries around. Although some people use the term "systems approach" to be holistic and inclusive, our use of the word "systems view" specifies a set of intellectual tools that can be applied to any size set of processes and resources.

5.2 Model Components

There are five components that we will use to represent the structure and behavior of our chosen system. For example, look at the growth of a population of rabbits (see Figure 1). This figure contains the five main components that we will use, stocks, flows, information flows, convertors/constants and a source/sink. Each component is represented by an icon.

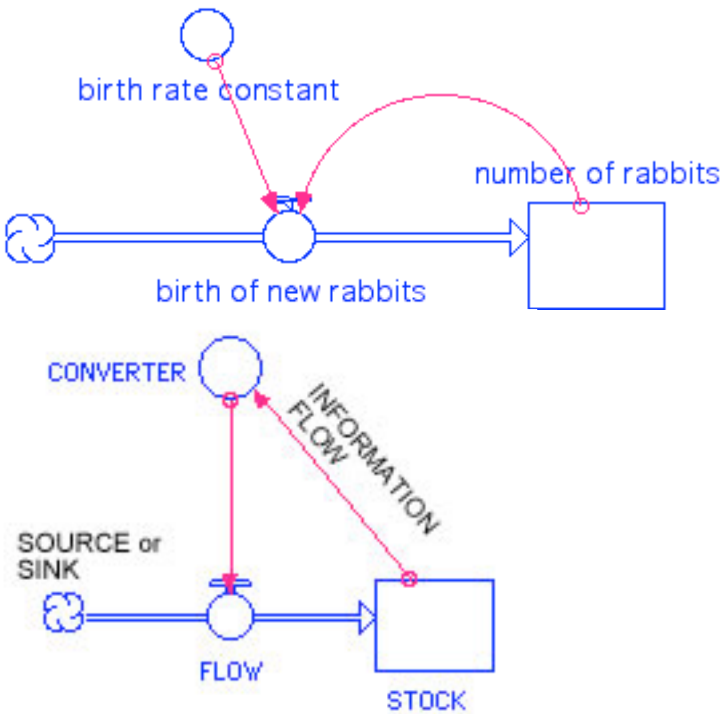


Figure 1. A simple systems diagram for the increase in a population of rabbits illustrates the five objects that we will use.

Stocks are a quantity of something. Water in a tank is a good example of a stock. Sometimes stocks are called reservoirs. All the stocks that are connected with flows will have the same units, that is all the stocks will be a quantity of water, or an amount of carbon, or the number of people, etc. In our example, the stock is the number of rabbits in the population. We represent this in a systems diagram with a box icon.

A **source or sink** is either has an unlimited, unchanging concentration or they are outside of the system that we are studying. In our example, the source of new matter that supports rabbit growth is not being considered. You can easily imagine another model where the amount of food available to the rabbit population limited the amount of new rabbits being born. In this case, we would probably model the system to include the nutrients as a stock rather than a source/sink. A source/sink is represented as a little cloud in our diagrams.

Flows connect stocks or source/sinks. The flow will increase any stock that it flows into or decrease a stock that it flows out of. All the flows that are connected to a stock will have the units of whatever the units of the stocks are per time. For example this could be liters of water per hour, tons of carbon per year, or in our example, rabbits per month.

When we have information that is needed in the model as a constant or we need to make a calculation, we show that as a "**converter/constant**". In our example, the growth rate constant for the rabbits was given as a constant. In the diagram, this is circle.

Information connectors illustrate the flow of information, not material, from other components to either flows or converters. Information cannot flow to a stock because the stocks can't do anything with that information. In the simplest form, an information flow simply notifies an action of the concentration of a stock, the rate of flow, or the value in a converter/constant. In our example, information flows brought in the values of the growth rate constant and the number of rabbits to the "birth of new rabbits" flow. The flow is calculated as the growth rate constant times the number of rabbits. The icon for this is a single line arrow.

These five components can be used in very flexible ways to describe the structure of different systems. An important value of this approach is that the structure indicates particular types of behavior of the system. In our example of rabbit growth with unlimited resources (indicated by the source/sink tool), the population would grow exponentially. As there are more rabbits, the number of new rabbits per time period will get bigger, leading to an even higher population of rabbits, and so on. A mathematical model of this population growth would give the following type growth shown in Figure 2. (Of course the population can't continue to grow like this forever.)

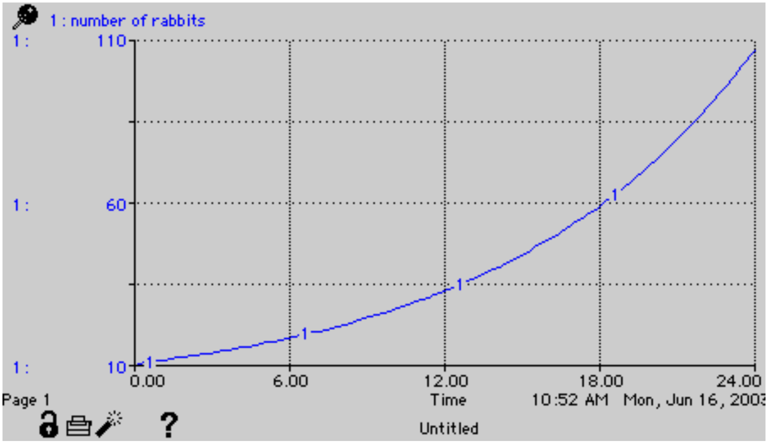


Figure 2. Rabbit population growth predicted from the model in Figure 1. The initial rabbit stock was set to 10 and the growth rate constant was set to 0.1 per month.

The structure of this particular model is a positive-feedback system. As the stock increases, that increase positively affects that flow that is leading to that stock. Many biological systems have this structure and function as part of their overall regulation. Sometimes this is good, such as in the growth of food crops and forests, the more crops or forests the faster they grow. Sometimes this is a bad feature for humans such as the spread of a disease (the more infected people, the faster the disease will spread) or the growth of invasive species.

We will examine several "simple" structures that are very common. These simple structures can be combined in larger models to describe very complex and busy processes. For example, if we were to create a model for global warming it would have positive and negative feedback components, open and closed systems and steady state structures included making up the full model. These "simple" structures that we are starting with are like the sentences in a larger document. You might be able to understand the individual sentences but not understand the entire document, but it is very likely that if you don't at least understand the sentences, you won't understand the total document.

5.3 Model structures and behaviors

The following structures and behaviors can be found in many larger systems models. The analysis of a system should start with determining the extent or boundaries of the system as you plan to study it, and then look for smaller structures and then how these smaller units are related.

Boundaries of the system – The first step in studying or communicating information about a system is to explicitly define the boundaries to our description and what flows in and out. A "closed system" is one in which there are no source/sink components. All the flows occur between stocks. Often the decision of whether or not a system is open or closed requires a judgment based on the significance of some of the smaller losses or gains and a decision on the time scale of your study. For example, you might model a forest as a closed system for nutrients ignoring initially small amounts of nitrogen that comes in from rain or lost through streams. The time scale question is apparent if, for example, you are studying the gain and loss of species in a city park but are ignoring evolution. The description and diagramming of a systems model should attempt to make these boundaries very clear.

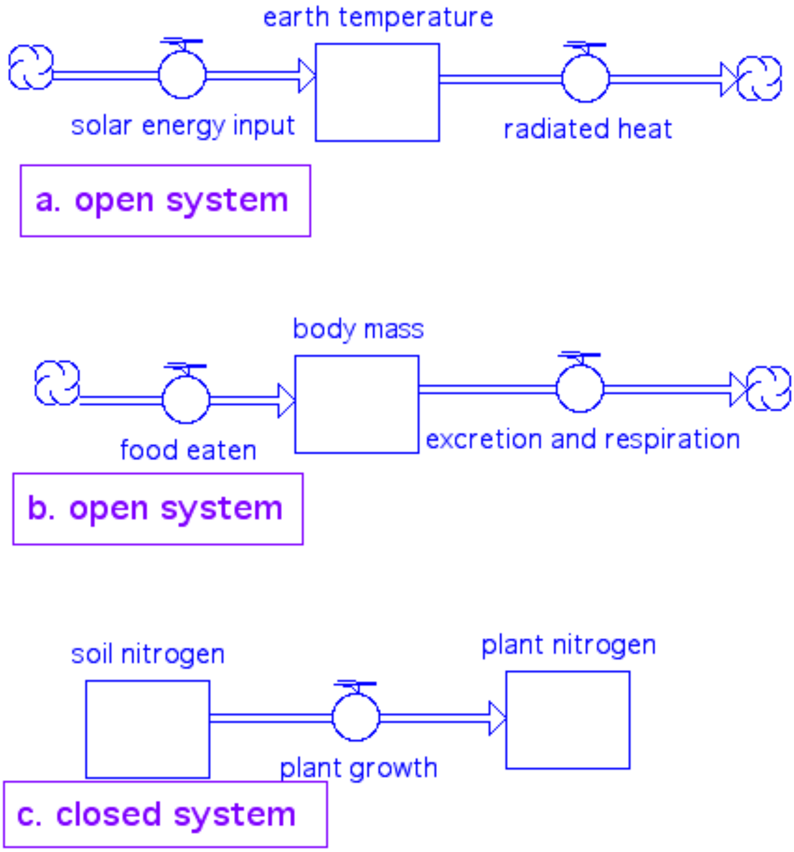


Figure 3: Several examples of open and closed systems. a and b are open, c is closed.

Positive and negative feedback - A stock that controls the flow into that stock can be described as having a negative or positive feedback. Sometimes we will talk about positive or negative feedback "loops" which are when stock A controls stock B which in turn eventually controls the flow into A. These feedback loops are crucial characteristics of systems control. Figure 1 was an example of a positive feedback and the example behavior given in Figure 2. Figure 4 shows a system that contains a negative feedback system with an example output.

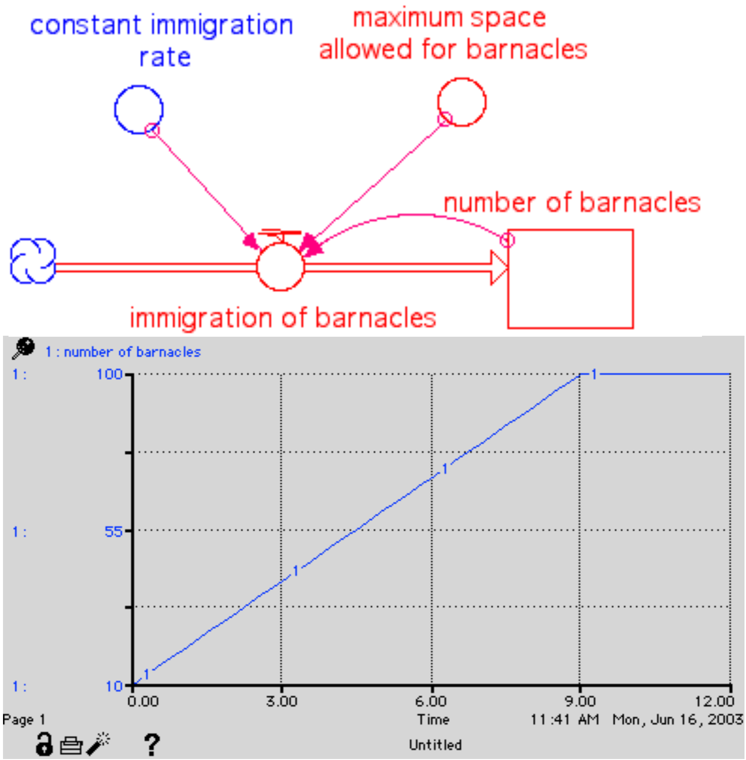


Figure 4. A system that contains a negative feedback control (shown in red, or slightly gray). The system wouldn't work without the other components. The number of barnacles continues to increase until it hits a maximum and then it levels off due to lack of any more space.

Stock limitation - One of the powerful applications of the systems approach is to examine the constraints over extended periods of time. Some of these are mitigated by feedback inhibition and others are exacerbated by positive feedback. Stock limitation is an absolute limitation on the amount of a stock that can flow to other stocks or an ultimate sink. Examples of stock limitation might be the seasonal availability of nitrogen in the soil, the space trees to grow, or the amount of fossil fuels available for human consumption. Figure 5 presents two variations on a model for bacterial growth, one with and on without stock limitation.

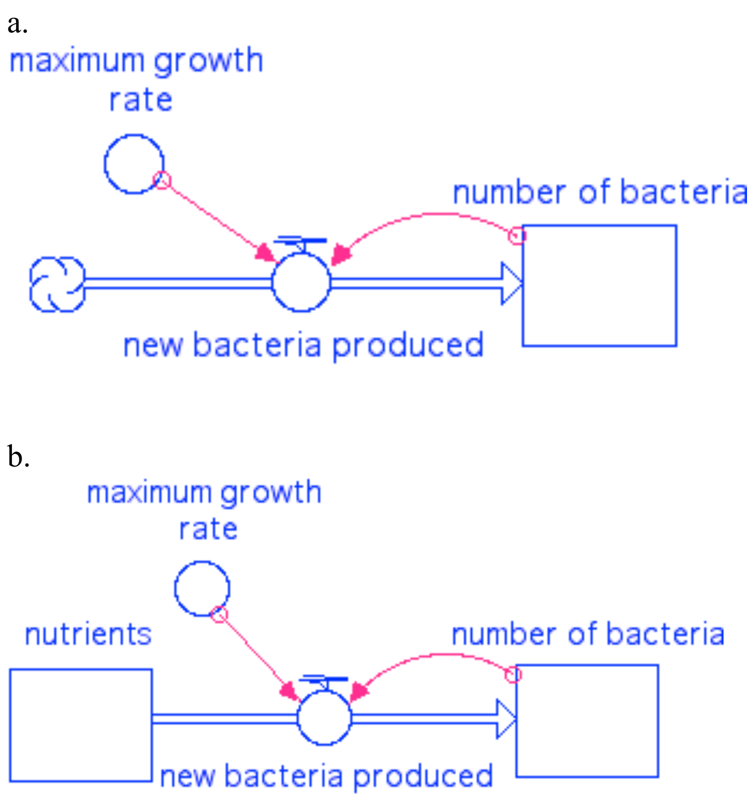


Figure 5. Stock limitation model for bacterial growth. The stock is the amount of nutrients in the container. In model "a" there is no limiting stock, in model "b" when the limiting stock runs out, the new bacteria production rate is forced to stop.

Steady state - The inflows to and outflows from a stock can create a situation where steady state is possible. If the sum of all the inputs is equal to the sum of all the outputs then the value of the stock will not change with time. A slight increase of the input or a slight decrease of the output rate can lead to an increasing stock. Figure 6 illustrates a familiar example that relates to body weight. Other examples of steady state conditions are the CO2 concentration in the atmosphere (currently not in steady state), use and replenishment of natural capital, or the human population at zero population growth.

The conditions that lead to steady state are important to understand because the steady state may be the consequence of a very slow input and very slow output, in which case not much will ever happen very quickly. Conversely, the steady state could be a very tenuous balance between rapid input and output. With rapid fluxes, slight disturbance in one rate could have dramatic consequences. A good example of this delicate balance is a pond in which a large amount of algae growth is growing and contributing oxygen to the water, but then with a slight change in temperature the large amount of algae turn from a net oxygen producer to a net oxygen consumer. These ponds crash into a scummy mass very quickly and then start to stink. Simpler natural systems may be controlled by just a few rapid fluxes and when one of these processes changes those natural systems can flip to a whole new behavior. We will also examine the stability, instability and resilience of these environments in Chapter 7 using the network view.

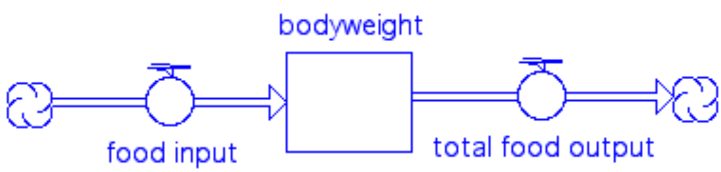


Figure 6. An example of a familiar steady state problem. If the input equals the output for a stock, the stock will remain constant with time, no matter how fast the input and output are. If the input exceeds the output, then the stock will increase. In this case food input is in terms of the weight of all food eaten and the food output is the weight of all excretion of waste, including the CO2 exhaled. The variable part of the bodyweight is “food storage”.

5.4 Simple and busy models

We have shown several "simple" models above. These models have a few components or strings of components and all the units for stocks and flows are related. Expanding these examples, there are other simple models that might contain two parallel paths. For example modeling energy and nitrogen in an ecosystem requires two sub-models; one for nitrogen and one for energy that are linked by information connectors. These should be treated as two simple models that have some interacting control points.

The point of using the systems view in this course is to take a complex set of processes and try to simplify it to just a few components that describe the control over the behavior. Then this model of the system can be used to make predictions about different controls or perturbations.

Several examples of simple and slightly busy models are given below. For each of these examples an analysis is provided that serves to demonstrate how you can use this to understand environmental problems.

Example 1: Changes in human population in a country.

The population of a country is determined by the current population plus additions from births or immigration and minus losses from death or emigration. If the birth rate is higher than the death rate even by a little bit, the population can experience an exponential growth rate. In many countries, industrialization has lead to a decreased death rate followed by a decreased birth rate. The overall side effect of industrialization on the population has been to stabilize of population size. Some countries however, are stalled at a level of industrial development that has resulted in a decrease in the death rate but left the birth rate high. These countries are experiencing rapid population growth rates.

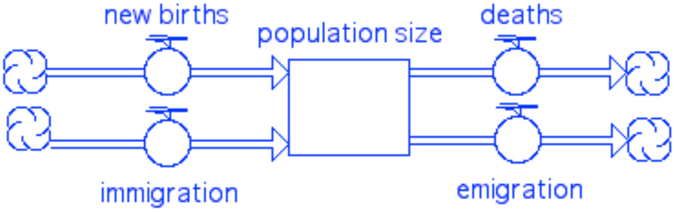


Figure 7. Population change. The population increases from birth or immigration and decreases due to emigration or death.

Analysis - The population is the only stock in this system. All of the inputs and exports are out of the system, which only means they are not being studied in this model, not that they aren't important. The population is a possible steady state situation. Notice that this version of the model has left out the control of births or deaths by the population size itself. (See Figure 1 for how it should be written.) This diagram illustrates clearly that we need to understand the relative rates of all of these processes to predict what will happen with this population.

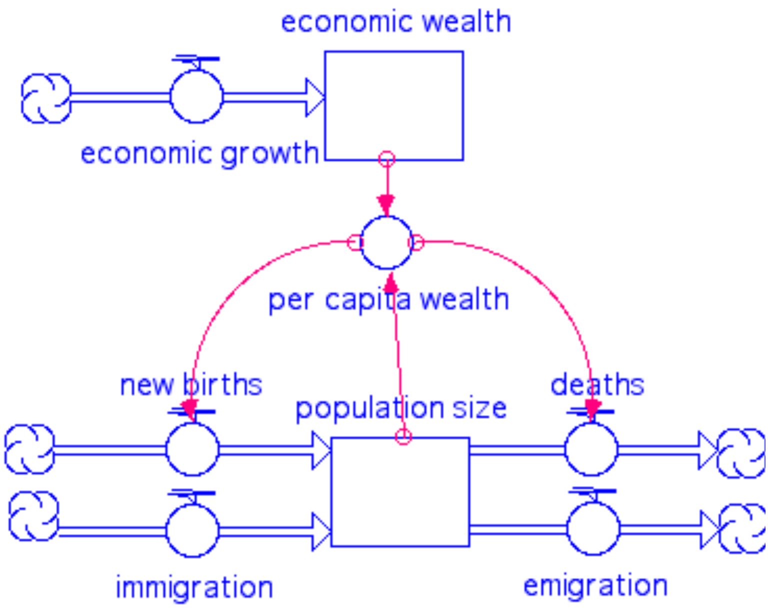


Figure 8. Busier model of population change. Economic growth in a country (which can be the result of industrialization) creates wealth. The economic wealth per capita is the total economic wealth divided by the population at any time. In models of population growth, a decrease in death rate is correlated to an initial increase in per capita wealth. If the economic wealth per capita continues to increase, families may choose to have smaller families and thus decrease the birth rate. This example doesn't claim that increased wealth causes the decrease in population growth rate, only that they are correlated.

Analysis: This model contains two simple models that are connected through the "per capita wealth" convertor. Economic growth will increase the per capita wealth and increases in population will decrease the per capita wealth. This model illustrates that if the economy grows more slowly than the population, it may result in higher per capita wealth and then in a decreased birth rate. This may lead to a slowing of the birth rate to allow a steady state population. However, if the economy grows just enough to decrease the death rate but the per capita wealth doesn't increase after that point, the population will continue to grow exponentially. This relationship between population and economic conditions are the basis for studying demographic transitions that occur. In Northern Europe, the United States and Japan, for example, the industrialization and economic growth has lead to what's called the classical demographic transition. We will revisit the systems description of demographic transitions when we study how different worldviews treat the risks of population growth and forecasts for economic growth (Chapter 11). The systems analysis of this problem can be combined with other frameworks to provide further help in describing and making decisions.

Example 2: Global warming and CO2 in the atmosphere.

Global temperatures and the CO2 in the atmosphere are linked at multiple layers. The "busy" model diagram below shows how several simple models are linked.

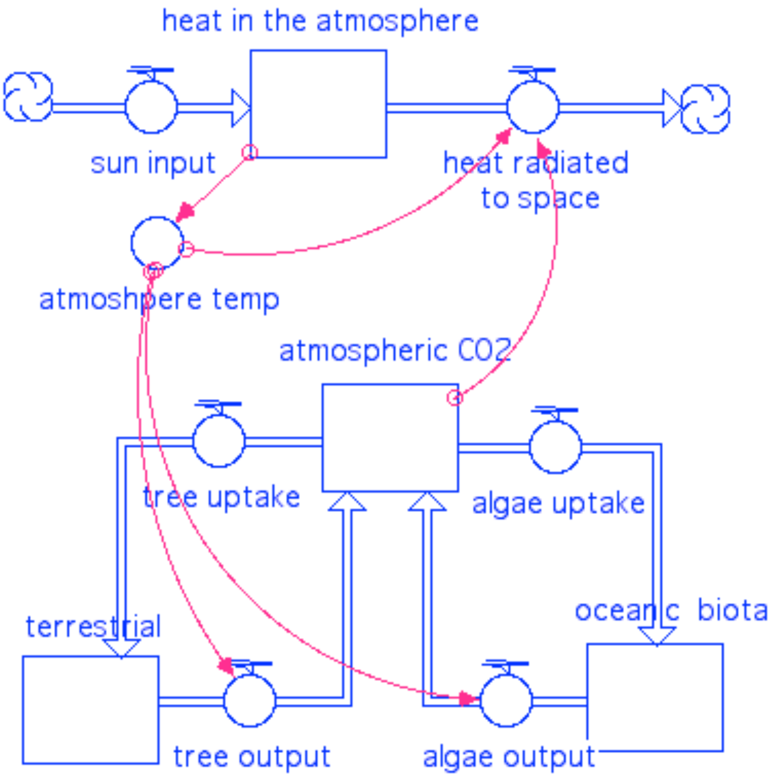


Figure 9. A busy model of atmospheric temperature and the geochemical cycle for carbon. The analysis, below, identifies the simple model parts and the linkages between these sub-models.

Analysis: This model is missing many important stocks and flows. Even with this flaw, it is useful to analyze the structure and potential behavior of the model.
The top part of the model shows that the atmosphere could potentially be in steady state for heat energy. The sun energy comes in and the heat is radiated back out. The amount of CO2 in the atmosphere makes the net efficiency of irradiation back into space less efficient, requiring a slightly higher atmospheric temperature to reach a steady state for the energy (heat) in the atmosphere. This is called the "greenhouse effect".

The bottom part of the model shows two major fates for CO_2 from the atmosphere, either going into ocean or terrestrial biomass. In this version, the only controls that are shown are the increase in respiration rates of the terrestrial and oceanic plants from higher temperature. The bottom part of the model is tracking carbon.
Notice that the top part of the model is tracking energy and the bottom part of the model is tracking carbon. There are no flows between these two halves, only an information connection and converter. The linkage of these two sub-models leads to a potentially very important behavior, run-away positive feedback of the temperature. The scenario is the following:

1. the atmospheric temperature increases,
2. which increases respiration from terrestrial and aquatic biota,
3. which leads a higher steady state of CO_2 in the atmosphere
4. which, in turn, leads to higher temperature
5. and it continues

These two examples provide studies in how the systems view is valuable. Example 1 shows how to take a simple model and combine it with another simple model to study the potential interactions between processes. Example 2 shows how to dissect a model into the simple sub-models, analyze them and then put these all back together to study the overall behavior and look for potential problems.

5.5 Starting Steps for Using the Systems View

1. Identify what material or energy is being moved.
2. Identify what the reservoirs are and how material or energy moves between these reservoirs, i.e. the flows.
3. Draw a boundary around the system you are studying: what stocks and flows are you quantifying and what is outside. If

there are flows in or out of your target system, then these must be represented by sources or sinks, respectively.

4. Create a diagram that shows the major reservoir stocks, flows, sources and sinks using the iconography supplied above.
5. Are there any conditions (such as temperature) or derived quantities (such as flow per person) that might be controlling a flow? If so, create a converter or constant to represent this relationship.
6. Make linkages from stocks to flow-regulators, from one flow to another flow, and from convertors to flows.
7. Check the diagram to see that all flows represent movement per unit time of whatever is in the stocks.
8. Examine the diagram for the regulatory components within a flow such as feedback inhibition (negative feedback), feedback acceleration (positive feedback), stock-limited flow.
9. Examine the diagram for relationships between the flow of different material or energy (such as use of natural capital vs. the rate of population growth).

5.6 Overlaps and conflicts with other viewers

A full list of the overlaps between viewers is provided in Appendix 4.

Term in "Systems"	other viewer/term	similarities and differences
boundary	scale/extent	Everything outside the boundary of the system is either neglected or is an unlimited source or sink. In the Scale viewer, extent relates to the size of the largest dimension considered, the word doesn't imply any process or specific border.

stock	network/node	A stock must be something measurable that can be moved through a flow. In the network view, a node can be a quality that changes depending on input links.
flow	network/link	A flow must be the movement of material or energy per unit time and whatever is flowing has to be the same as the stock at either end. A link identifies a relationship between nodes. It can be a quantity of material moved but it doesn't have to be a quantity.
stability	network/stability, resilience and resistance	Systems models can reach steady state that has some stability due to some form of negative feedback that keeps it at a level or in some range. The type of systems model that we are using doesn't have a mechanism to change its own structure. A network diagram that has many weak interactions can shift the operational structure and show how a large number of weak interactions or the combination of fast and slow processes can lead to the resilience or loss of resilience of the network.

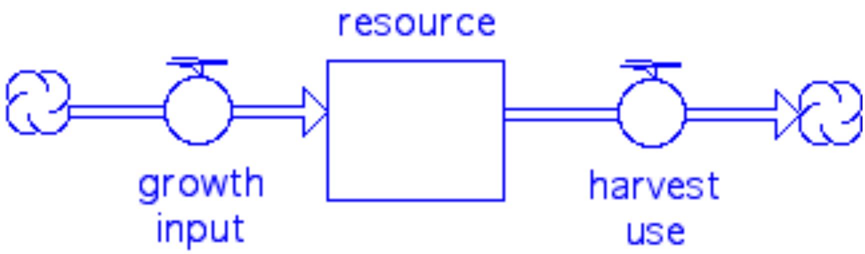
5.7 Going to the next levels

An important extension of the use of systems models is to create simulations that demonstrate overall system behavior given certain input conditions and constants. We will look at the components of the system, such as positive or negative feedback to look for very general system behavior. There are software applications that are useful for turning these systems diagrams into mathematical dynamic models (the diagrams and charts in this page were generated with STELLA from High Performance Systems, http://www.hps-inc.com). See the website for this book to see simulations that were written in STELLA and simulations made available on the web (through Forio.com). These simulations can only have changes in the parameters, not changes in the model structure, but are very useful for illustrating the types of predictions and uses for simulations.

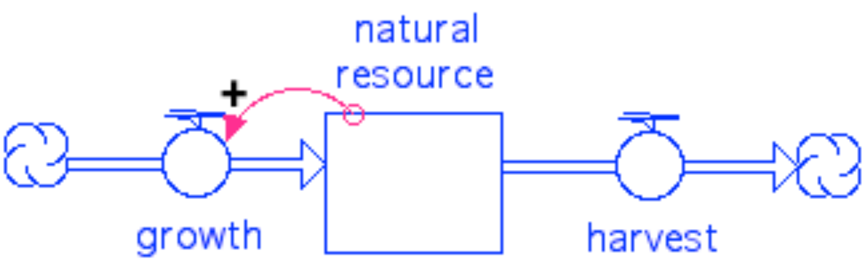
Simulations of this type are extremely useful in modern decision-making. For example, scientists could create a complicated and very busy model that contained information on fish, dams, river flows and electricity. This model could be run under different climate conditions and demands for energy to show which parameters affect fish survival most. In addition, the model can be shown to people who work in this arena of fish and rivers to see if the model behaves in a way they think it should; does it show low fish years when expected or high fish years following particular events? The simulation model and the accessible interface are powerful tools in addressing problems and getting people to learn about complicated social, economic and ecological issues.

5.8 Developing a simplified Systems model of sustainable resource use

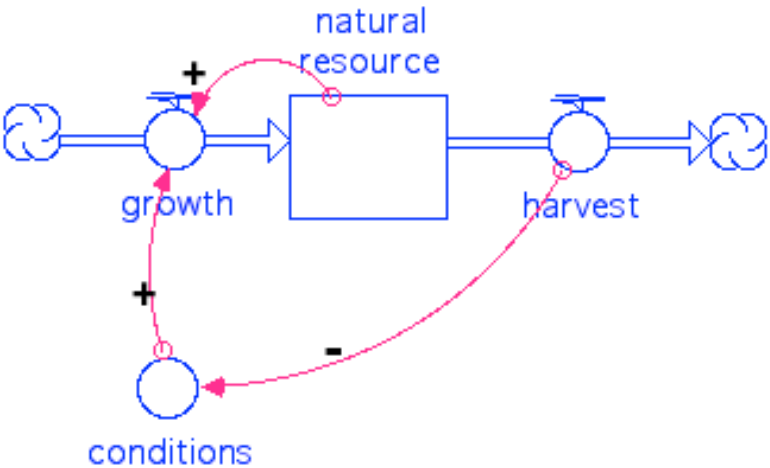
Many people subscribe to the idea that a sustainable resource is one in which you reach a steady state because you don't use the resource faster than it is being created. Whether or not this is required for all resources to attain a sustainable society is a very interesting question. There are different definitions of overall sustainability that address the entire ensemble of capital types. We will focus here on the sustainable use of a single resource. For example, you would harvest the wood at the same rate as new trees were growing to replace what you took.



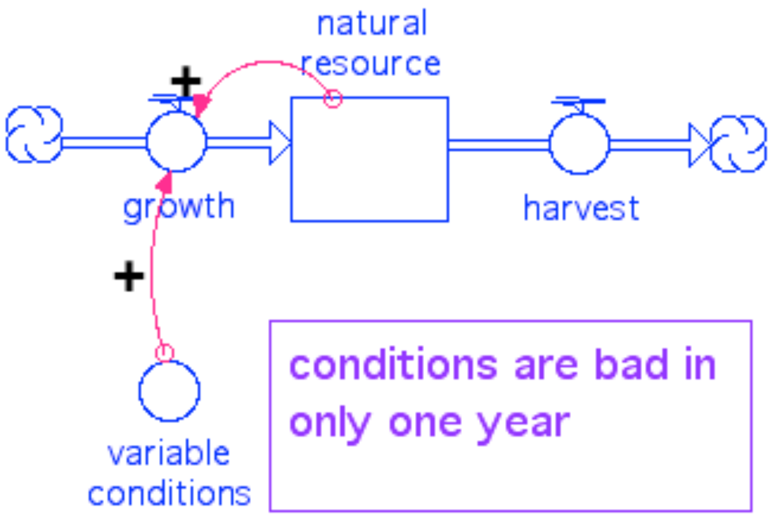
If this resource is based in natural (biological) capital the growth rate will often depend on the amount of the stock. For example health fish populations grow faster with more fish and even a trees will grow better in a healthy forest with lots of other trees to provide protection and a suitable micro-climate. Although it isn't always the case, let's model the natural resource as having a positive relationship to the growth of new resource.



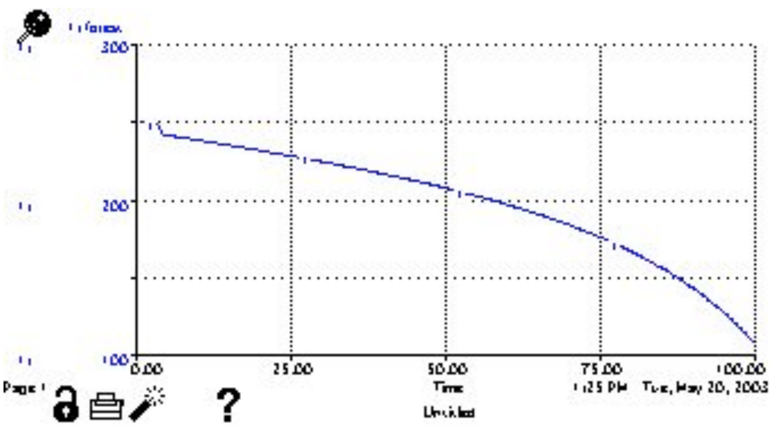
When we harvest the resource, we might just be removing the fish or trees, but we can also be degrading the environment that the fish or trees need to grow. For example, driving bulldozers around on the soil and channelizing streams in steep watersheds has a negative effect on forest health. Similarly, some fishing methods disrupt the breeding areas for fish. Thus the harvest has a direct take of the resource but it can also degrade the conditions leading to a decrease in the growth rate. Notice in this case that a negative effect on conditions is passed through to impact growth because there is a positive relationship between conditions and growth: worse conditions lead to lower growth.



Another important issue with natural resource management is the impact of bad (or good) luck. What if you were managing a forest that had an average growth rate but there was a single drought year that decreased the input to the resource by 50% just for that year. If you had a harvest plan that was even just 5% more than the actual maximum yield you could harvest, it would lead to a decrease in the population that would never recover (assuming you don't stop harvesting after you see the population start to crash).



The effect of one bad year (only 50% output) and an underestimate of true maximum yield by only 5%. In 100 years you're down to less than 1/3 of your starting natural capital.



Using this simple model of natural capital and sustainability illustrates that there are at least three ways to destroy the sustainability of your natural capital

a. simple overharvest, but this may be because you didn't have good estimates for the maximum yield

b. indirect effects from either harvest or use
c. risk of being too close to the maximum yield, one bad year and the resource declines dramatically

5.9 Case Study: Population and Environment of Easter Island, Rapa Nui

Easter Island (also known as Rapa Nui) is a small island in the middle of a very large ocean. The area of the island is only 166 km^2 (64 mi^2) and it is 2250 km from the nearest other island (Pitcairn Island) and over 3700 km from South America, the nearest continent. You have undoubtedly heard something about this fascinating island related to speculations on what caused the population to crash. In fact, you've probably heard more about this island because of this failure to be sustainable than you've heard about any of the myriad of other islands in the South Pacific.

At one time in the history of this island, the society had fairly sophisticated culture and technology. The cultural history describes a well-developed hierarchy with laws and written script. The evidence of the technology was their ability to move the large stone statues, which the island is most known for, for long distances. They moved carved stone sculptures that weighed up to 82 tons as far as six miles (10 km). The islanders cultivated a large part of the island with multiple crops. Estimates of the maximum population on the island ranged from 7,000 to as high as 20,000. And yet the population and civilization must have crashed. When European boats first recorded their interaction with the island (in the 1700s) the population was only several thousand, and these people were leading a tough life in a very desolate environment.

You can see from just the outlines of this story why the island's history has always been so intriguing. Now with our interest in sustainable systems, it is important to attempt an understanding. There are parallels between their tiny island in the mid-Pacific and our planet in the mid-Milky Way. Once the environment started to decay and subsequent crash of population and society, these islanders had no place to go. Sustainability isn't just about maintaining a mere subsistence life style, it's also about continuing to develop the culture and have a healthy physical existence.

In this case study, we are going to examine the population, agriculture and land use practices that were employed on Easter Island from about 400 AD to about 1700 AD. We are going to analyze the very gradual depletion of the natural capital on Easter Island using a "systems" approach.

A more complete story

A more complete story can be found at the following sources:

> Wikipedia:
> http://en.wikipedia.org/wiki/Easter_Island
>
> Discover Magazine: Jared Diamond. “Easter’s end.” Discover magazine, August 1995. 16(8): 62-69.
>
> TED talks such as:
> http://www.ted.com/talks/lang/eng/jared_diamond_on_why_societies_collapse.html
>
> http://blog.ted.com/2008/10/27/why_do_societies_collapse/
>
> Diamond, J. (2005). Collapse: How societies choose to fail or succeed. New York, Viking.

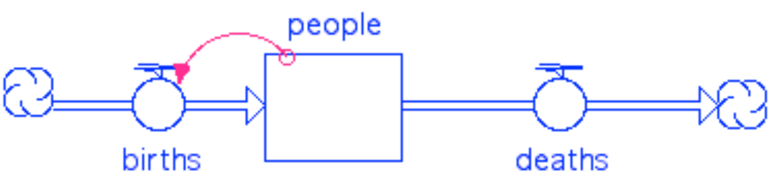
Salient features

The story of Easter Island has particular features that make it amenable to examination with a systems approach. First, it is very similar to the systems model for sustainability that we developed in section 5.C; there are suggestions of growth, harvest, and bad luck. Second, at any time the processes seem to be close to being in balance; it is only by looking at the long term effect of these do we see the impact of a slight over harvest or a previous year of bad luck. Third, the description contains some simple models that could be tied together to get an integrated picture; there is population growth, harvest of trees, soil moisture, agriculture and fishing. These processes are related, but not directly.

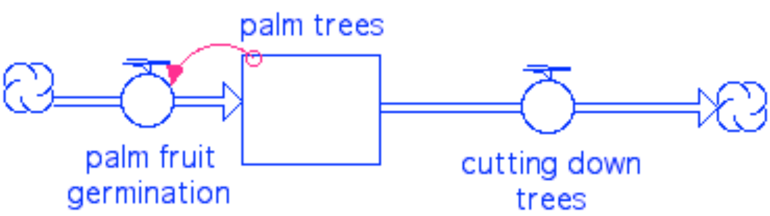
Applying the systems viewer

The approach that we are going to take is to put separate small models together and to examine how these individual processes counter or reinforce each other. This is an oversimplified model in which will only consider three stocks: the number of people, palm trees, and rats.

The number of people is the balance between birth and death rates. As there are more people, there will be more births, i.e. the population growth has a positive feedback component. The number of deaths may depend on many other factors including natural causes, famine, and disease. A simple model diagram for this is given below.



The number of trees is also a balance between the number of palm nuts that germinate and grow, and the cutting down of the trees.



The third strand in our model will be the rat population. People brought rodents to the island. These rats play a key role in this problem. People eat the rats and the rats eat the palm fruit, decreasing the tree population. Their population is just like the others, there is positive feedback for rat births and several factors controlling death.

Now we are going to connect these three stocks and flows models with factors that affect either the birth or death rates. The following list details these interactions.

1. Rats have a positive effect on people births. The birth rate of people will increase with more rats (and the birth rate will decrease if rats are low).

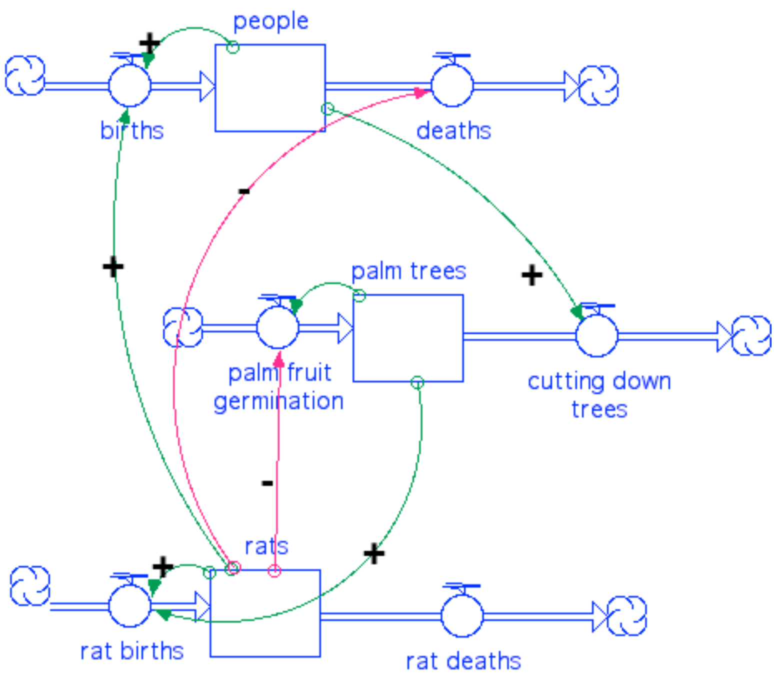
2. Rats have a negative effect on human death. The death rate of people will increase if rats are too low.

3. People have a positive effect on the harvesting of trees. More people cut down more trees because they need them for fishing and to cultivate land for crops.

4. Rats have a negative effect on the rate of palm fruit germination. The number of rats decreases the percentage of new palm seeds that germinate successfully because the rats chew on the seeds.

5. Palm trees have a positive effect on rat births, because the rats eat the palm fruit.

We could add more detail to this model, but even with only these five interactions this turns out to be a very interesting and instructive model. Looking at the model diagram, below, you can see that there are many positive feedbacks and only a few negative feedbacks.



According to the historical record, as the human population grew, people cut more and more trees. They needed these trees for making boats for fishing and they needed more and more land for cultivation. Over harvesting trees, just on its own would have been a problem for them, but this was exacerbated by the fact that they also ate rats, and rats depended on the trees for food. As the human population continued to grow, they cut enough trees such that they ran out of trees to use for fishing. Simultaneously, with fewer trees they not only couldn't fish effectively but their other food source, rats, declined.

The model built here only represents a few of the interactions that have been described. By putting these into a systems diagram, we can explore the possible behaviors of the individual populations and their effect on each other. It is possible that the population could have also reached a balance. There is nothing inherent in the structure of these relationships that makes it crash. However, the balance comes about because all of the relatively rapid rates of all the processes are cancelling each other out, but a minor imbalance in the rates can lead to abrupt changes in the whole system.

Multiple Perspectives V4.2

Chapter 6 - Scale

6.1 Introduction

One of the most useful beginning steps for addressing a problem in Environmental Science is to determine the time and distance scales of the objects and processes. This helps you identify the main processes and provides an estimate of their magnitudes. The second level of inquiry is to make observations that deliberately span several scales. The third level, which is very challenging, is to study how the processes work across scales. Each of these levels builds on the information from previous level.

The three levels are described below with examples of how they can be applied to environmental problems. One important aspect of the scale viewer is that this approach sets up the use of other viewers; in particular the systems viewer depends on knowing the major processes, objects and boundaries of the system being investigated. So even though the viewers provide different information about the problem, information from one can compliment and support other perspectives.

6.2 Identifying scales of physical objects and processes

This level is both quantitative and descriptive. The goal is to identify the major objects and processes and then estimate a range of characteristic of time and space values. For example, if part of the study deals with the interaction between birds, trees, and insect damage, then the characteristic space scales for birds would be size/weight and foraging range. Similarly the trees size and distance to neighboring trees might be important. In both cases the range of size of birds, trees and insects could also be of interest if it is very broad. The processes of interest would probably be the growth rate (time to reproduce), the insect spreading rate (distance that the infestation moves per day), and other weather processes or disturbances that might affect the health of the trees, birds or insects. These ranges should all be listed in consistent time and space units (such as days and meters). Some example values are given in Table 1 and these are visualized in the accompanying Figure 1. Note that log-log axes are used (log of time vs. log of distance) because there is a wide range of values.

Table 1. Example of scales in a small forest system. Sizes are given in cm and characteristic time constants are given for processes.

insect size - 0.5 to 4 cm
bird size - 10 to 30 cm
tree size - 5 to 30 m
insect doubling time - 10 days
bird doubling time - 40 to 80 days
tree doubling time - 5 years (1500 days)
drought frequency- 1 every 10 years (3650 days)

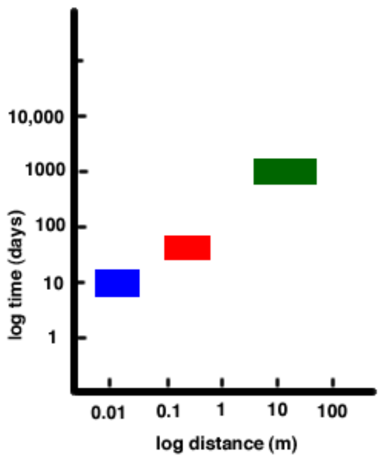


Figure 1. The green is trees, red is the birds, and blue is the insects.

Examine the texture of your surroundings.

Another way to interpret the effect of scale is to examine the "texture" of the study area. As you look around, what are the relative sizes of objects and how many are there. An easy example is looking into a stream pool that is about 1 x 1 meter. You may see a range of rock sizes from little pebbles to larger cobble. The texture of that system would be determined by the relative distribution of different rock sizes. A comparison of the texture of two streambeds is shown in Figure 6.2.

Figure 6.2 a) Boulders in a stream in Candalaria, Spain. This stream receives heavy flows during the spring runoff from the Gredos Mountains. Strong stream flow can move very large boulders. Thus the "texture" of this stream has a large number of

larger boulders than would a small, slow flowing stream. b) By contrast a small stream in Yellowstone National Park that has a bed of small rocks in a sand bar. The forces that caused the texture of this feature are much less than above.

Or consider that you are doing a study in the middle of a pasture or meadow, there maybe very little texture that is obvious from your vantage point but if you do transects across the meadow you may see patterns of grasses that relates to the underlying soil types and moisture. Several 10 meter transects in different directions may help illuminate this structure. An aerial image of the Zumwalt Prairie in NE Oregon was analyzed for different types of ground cover (just by color). The percent of different vegetation/color types found is given in Figure 3.

Figure 3 -An image from maps.google.com that was analyzed for the color of vegetation using Photoshop. This image is from Maps Google (Google - Imagery ©2010, USDA Farm Service Agency, GeoEye, State of Oregon, Map data ©2010 Google).

The texture of these environments points to likely underlying processes and is very important for the organisms that exist at these scales. For example, in this little patch of the Zumwalt, small birds might have to flit from one stand or clump of trees to another to avoid the legendary number of birds of prey in this region. Please see the Nature Conservancy's description of this reserve at these two links:

- http://www.nature.org/wherewework/northamerica/states/oregon/preserves/art6813.html
- http://www.nature.org/success/art17838.html

Look for homogenizing processes

One of the crucial impacts that humans have on their environment is that we tend to homogenize small-scale landscape diversity and sometimes even across large scales. Much of this impact is from intentional projects that are designed to provide benefits to humans. Some of the most obvious anthropogenic effects are leveling of the ground, habitat destruction and construction of roads. The worry over "habitat fragmentation" is not that humans are breaking up homogeneous habitats, but rather that fragmentation allows the incursion of other forces into the middle of otherwise highly diverse and rich natural environments. Habitat simplification and the construction of corridors for human commerce are actually barriers for natural processes and are evident at all scales in the human/nature interface. For example, there are roads that range from only several meters across to super-highway complexes (especially the interchanges) that are several kilometers across. Roads and traffic often are a severe constraint to animal movement within their natural range. It has been claimed that there is nowhere in the continental United States that is more than 20 miles from a road (including gravel and other access roads). The automobile and truck traffic on roads is dangerous to animals and the transport of invasive and nuisance plant species is harmful to native vegetation. Road Ecology is emerging as an important sub-discipline to address the impacts and possible mitigation efforts.

Figure 4. Road impacts are so severe in some places that special highway overpasses or tunnels have to be built to allow safe passage of animals within their normal range. (Image from http://www.huntingvt.com/wildlife-pictures.htm: downloaded 9/13/2010)

Identify edge effects, dissipation zones and human energy intensity

These three concepts are related as they help describe the borders between human and natural areas and the coexistence of humans in a partially natural world. Consider a fairly cleanly delineated human/nature border such as a road along a park. The edge effect is the distance from the road into the natural area for which the effect is felt. This effect depends on the target species or community, it may be only meters for grass because cars don't disturb grass unless they drive directly on it, but it may be tens or hundreds of meters for small mammals or amphibians because any little turtle trying to cross that road may suffer a disastrous fate. If the road is between upland and pond habitats for amphibians, the edge effect might include the entire habitat for that animal.

A dissipation zone is the region for which the stress is greater than the natural growth capacity of the community. The dissipation zone deals with the direct release of energy from human activity. One example of a dissipation zone is along a roadside. In this case, it is similar to the idea of an edge effect. Other examples are the heat that is produced by a power plant warms the receiving water in a river or bay. In this case the dissipation zone is the region that has stress from the heat.

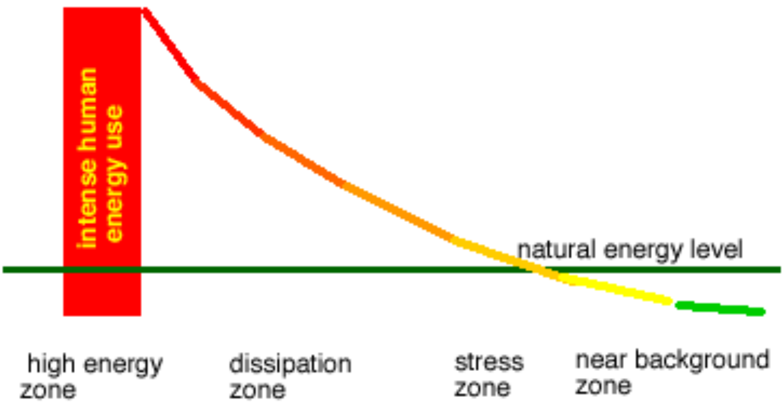


Figure 5. - Dissipation zones based on relationship to natural levels of power density.

One of the consequences of modern industry is that processes have been concentrated to allow for higher efficiency. This concentration leads to high energy densities at particular locations. Table 4 shows some areal power densities for common industrial activities. These power zones range from cars (15 kWatts/m^2), to American homes that might have an average power consumption of 5 kWatts and are 200 m^2, which leads to a 1 kW m^-2 power density. Nuclear plants for which the reactor generates 20 mega Watts and yet it is only 10 m^2 in size. The core of a nuclear power plants has about the same power density as the inside of a volcano (Ripl and Wolter 2002).

Table 4. Area power densities of different objects and activities in our society. (Conversion factors used are: 1 hp = 0.75 kW, 1000 kcal/day = 0.048 kW)

object	**area power density (kWatts/m^2)**
200 hp car - total size (10 m^2)	15
200 hp car interface with road (4 wheels x 100 cm^2 each)	3750
200 m^2 home or apartment that uses 120 kwhr/day	0.025
nuclear power plant core (20 megaWatt/10 m^2) ***recalculate size***	2000
human (2000 kcal/day / (1 m^2))	0.1
human plus subsistence agriculture (10,000 kcal/day applied over 1 hectare)	0.00005
solar energy input at noon in summer	1.4

6.3 Starting Steps for the Scale Viewer

Determine the boundary of the ecosystem area you are studying. For example, is it a watershed or multiple watersheds? It will be important to set this boundary large enough such that most of the processes are happening within the ecosystem, and the major processes are not crossing the boundary. For example, if you are studying a lake with only slow turnover and low river input, you could put the bounds around the lake. But if you were studying a lake that has high flushing rates from large river input and output, you'd need to include these rivers into your system for evaluation of the scales of the processes.

Identify the major physical features especially those that would determine process rates. These could be the volume of a lake or length of a river. At the smaller scales, the size of objects in the landscape is the "texture". For example, the size of trees in a forest or the size of boulders and riffles in a stream determines the texture.

Within this area and in consideration of the physical features, estimate the rate of important processes; don't forget to add in the long-term, slow processes. These often turn out to be some of the most important considerations. Intentionally look for processes that represent a wide range of rates, from seconds or minutes up to decades. Scanning for a range of processes in this way helps to avoid missing some factor that might be very important.

6.4 Designing studies

This is a simple version for what we are using in the lab. A more complete write up is available on the website for the course (http://web.pdx.edu/~rueterj/courses/ESM101/lab).

The objective is to use a variety of techniques that are at different scales

1. diversity quadrats (10 cm or 1 m)
2. multiple quadrants at random with in a 10 by 10 meter grid
3. take an informal transect by walking from one study site to another (about 1 km)
4. use a satellite map from maps.google.com or other to look at features of an area several km on a side

5. put the area you are studying into an current or historical eco-region based on soil type, dominant vegetation and climate

6.5 Level 3 - cross scale analysis

placeholder for next version

6.6 Mistakes we make when we fail to account for scale

Outline notes to be filled in for the next version.

Are there appropriate limits to growth rate or power input
- so that it doesn't overwhelm the natural powers (Adams 1988)
- or eliminate landscape for cooperativity in the future

Discount rate for calculating costs of environmental projects
- assuming one rate to hold across large difference in time scales is the mistake
- leads to:
    - unfavorable rates of return from ecosystem projects compared to financial markets
    - difficulty in assessing long term impact of environmental damage, such as global warming (see the Stern Report - www.sternreview.org.uk)

Rates are assumed to be constant if averaged over a long enough time.
- ignores the importance of dissipative structures and pulsing in self-organizing structures that control these processes
- the mean levels can't explain these processes

Different cultural views of time
- cyclic
- pulsing
- linear

Psycho-economic studies on perception of time and risk

- brains are "wired" to make decisions on short time differently than on long term
    - McClure et al Science October 15, 2004
- inability to understand how to slow down (Wolfgang Sachs 1999)

6.7 Scale effective solutions

Applied and mission-driven scientific research needs to provide workable solutions for environmental problems. In the past, I interpreted this effort as the attempt to understand some problem at a small scale, find a solution at that scale and then address the "scale up" issue. For algal culture work, this meant studying a process at the flask scale (< 1 liter), then going to bench-top (5 to 10 liters), then to proto-scale production (20 to 30 liter carboys) and finally to large scale (100+ liters). For lake ecophysiology, this meant studying the processes at flask scale, mesocosm size in lake bags (100 + liters), near shore transects at scales of 100s of meters. This "scale up" problem is a significant intellectual challenge. It is not as simple as just studying larger volumes. Often there are fundamentally different processes operating at different scales.

My new view of this is that we need to solve the problem at an appropriate scale (Schumacher 1973). This scale might be a small hydrologic unit of a marsh, a section of stream, or a part of a watershed. If I can find a possible solution can be proposed and implemented in this situation then it should be possible to replicate this solution many times rather than "scaling up". It is important that the solution meets the criteria of solving the problem AND being financially feasible. For example, it seems possible to provide drip irrigation for a small farm using solar power, a shallow water pump, some pipes, storage tank and drip tape. This solution can be applied to several acres and could pay off the investment over several years of selling market vegetables and fruit (such as watermelon). This combination of technologies fits this scale and is financially feasible. Installing drip irrigation not only breaks even financially but also provides social and ecological benefits that are much harder to account for with dollars. Other similar projects might be a small-scale pump that moves water through a wetland to remove phosphorus. The payment would come from incentives for P-removal. The benefits from increased marsh growth for migratory bird food or enhancement of fish habitat are side-products of the P-removal.

In both of the examples above, appropriate technology is applied to a problem at one scale and provides an "effective" solution. The goal is to solve the problem and provide economic, ecological and social benefits in the process. The solution is "scale effective" or in Wendell Berry's (1981) words, solves the problem "in the pattern" of the environment. This "pattern" may be the specifics of the topology of the watershed, the individual farmer's need for drip irrigation in one part of his land, or taking advantage of the diversity in fringe marshes to a lake. Instead of taking a solution and making it bigger, which is the common practice justified by trying to achieve "economies of scale" (an efficiency argument, this approach takes a solution that is feasible at one scale and simply replicate it over and over again.

There are other instances of small-scale technologies. We currently use networks of computers, cell phones, and other almost disposable individual products that are combined into a resilient and very durable network. Constructing a network of small, appropriate technologies can allow for turnover of the individual units that leads to incremental improvement of the unit design and the possibility for re-arrangement of the units in a process of self-organizing such as preferential attachment.

Scale-effective solutions start with scientific adaptive management driven inquiry (Norton 2005) targeted at the central scale of the problem. Part of that solution needs to be that the technology and process that is implemented at that scale is independently financially feasible. The other benefits (to individuals, the community, or natural capital) do not need to be documented or explicitly compared to the financial benefits, thus allowing a truly effective solution that focuses on the quality of the outcome (Drucker 2006). Then, instead of increasing efficiency by scaling up to larger scales with higher energy density and potentially increasing indeterminacy (Adams 1988, Pahl-Wostl 1998). Focusing on local solutions for small patches of the environment transforms the problem from attempting to finding an efficient solution of scale efficiency (following the traditional approach in which an intractable scaling-up process is required and may be one of the most difficult aspects of the overall project) to one that is looking for an effective scale solution that employs appropriate technology and looking for the highest quality outcome.

Simon Levin (1992) states that "the problem of pattern and scale is the central problem in ecology, unifying population biology and ecosystems science, and marrying basic and applied ecology" and claims that working across scales is one of the outstanding intellectual challenges for science and management. In my experience studying the history of the Klamath Basin and working with many people and agencies on these lakes, it seems that current lake restoration approaches reflect the general paradigm of science and industry, which is based on the assumption that there are "causes" to each outcome and that if we can identify the "cause" then we have to work to remove or minimize that factor. In addition, if there is a general factor of causation, then we can treat the problem more efficiently through large-scale application of whatever method we use to remove the factor. For example, the current thinking is that phosphorus is the factor that leads to lake eutrophication and we want to remove phosphorus input then it is most efficient (economically and policy) to do this for the entire lake basin. This traditional science/management paradigm also puts the scientist in the role of identifying the specific cause and passing information about that factor to managers in a policy neutral and "unbiased" manner. In particular, evidence for causative factors should be sought that are based on controlled experiments and a high degree of scientific certainty with little need for interpretation or judgment. As the management paradigm is shifting to a a more complex view it is expected that the scientist-observer will be more involved in all aspects of monitoring, observing, judging, speculating and innovating.

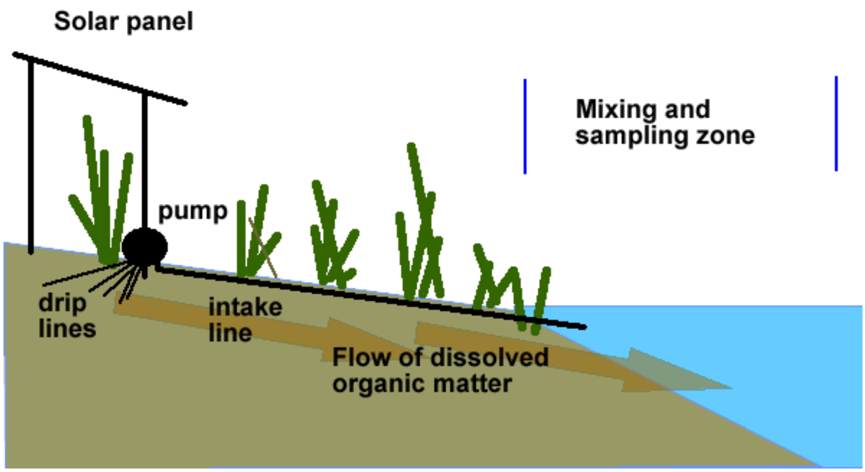


Figure 5. A schematic of using solar energy to pump water through a constructed fringe marsh.

The project described here shows the development of my research involvement in the Klamath Basin to be more active in proposing feasible solutions. This particular piece of work would simultaneously demonstrate that appropriate, renewable-energy technology could be installed at a small scale and demonstrate the environmental benefits of that project (reduced phosphorus in the lake, decreased algae in the lake, and wetland building). The project is also designed from the beginning to be replicable at this scale. If successful, there would be no need to redesign the technology to attain "efficiencies of scale". The project is effective at this scale and that can be simply expanded out. Although we may be proud of our large-scale civil projects in the past (dams, dredging, and levees), many of our previous successes turn out to be our present day environmental challenges. Small-scale projects that are networked together represent a new domain of human innovation (social and technological networking). For example, neighborhoods in San Francisco are joining together to buy solar equipment and get them off the grid (For Profit Activism – Economist Jan 29, 2009). The value of these networks is in their inherent flexibility, adaptability and resiliency.

6.8 Case Study: The importance of considering scale in lake treatment

Upper Klamath Lake and Agency Lake are two closely associated lakes in Southern Oregon. In fact, as a result of The Nature Conservancy breaching the levees last October 30 (2007), there is more connection between these two water bodies. Both of these lakes are shallow (average depth 4.2 meters) and hyper-eutrophic . According to the Atlas of Oregon Lakes (Johnson et al 1985) Upper Klamath Lake is the largest (by area) lake in Oregon with an area of almost 25000 hectares (62000 acres). The drainage basin is 9415 km^2 (3810 square miles) and includes Crater Lake to the north and the Klamath and Sycan marshes to the northeast.

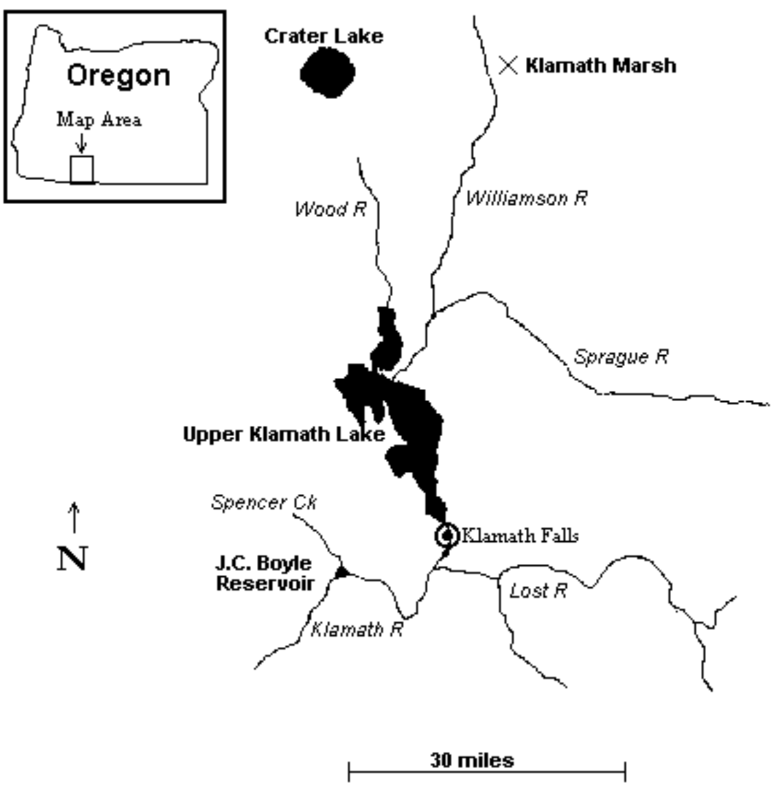


Figure 6. Location of Upper Klamath and Agency Lakes.

The water in these lakes is a valuable natural resource that is being shared by many people for many purposes. The general goal of the natural resource managers, citizens and scientists working in this area should be to understand this resource well enough to turn it into a sustainable resource that will maintain the freedom of choice for how the water and land are used by future generations. To do this, our society needs to meet two objectives; first we need to improve the current health of the lake (assuming that we don't want to pass a impoverished resource with few choices on to future users) and second we need to devise a plan to use the resource in a way that avoids irreversible traps. A trap is a situation that is easier to get into than to get back out, i.e. changes in state that is not easily or readily reversible. These two objectives are necessary conditions for creating a sustainable resource but still may not be sufficient to guarantee in any sense that the lake health and natural capital services will be sustainable.

In the grand context of these social, economic and scientific objectives for lakes, our group's research goals were much narrower. We wanted to help understand the immediate causes and mechanisms that lead to blooms of the cyanobacterial species *Aphanizomenon Flos-Aquae* (AFA), examine several existing hypotheses for the control of these blooms by either P interception or humic-rich marsh waters. An important part of the project for us was to provide this information in a context that will help manage these lakes for water quality and fish survival. Our research project is problem based, rather than curiosity based (Norton 2005). The situation in the lakes is that there is too much algae at some time that leads to decreased water quality and when the algal bloom crashes, the oxygen depletion is so severe that it leads to fish kills of the endangered suckers. This situation is a "problem" because we prefer cleaner water and we prefer to maintain the biodiversity of fish in the basin. Thus our problem-based approach reflects the values that society has for the uses of the lake.

Water quality and quantity is a "wicked" problem

Although a list of problems with Upper Klamath and Agency Lakes is standard (high nutrients, high chlorophyll, extreme alga growth, bloom crashes that lead to anoxia, disruption or death to endangered sucker populations), not everyone values the water in the same way. Of the major types of problems we usually deal with (simple, common pool resources, information and wicked), the water resources in this basin are definitely a "wicked problem" which have the following characteristics:

- people put different values on the outcome of having cleaner lake water
- as we develop more understanding of the lake system, some people's values change
- the problem is exacerbated by its history in which more water was promised than is available during many years
- there is a broad range of important space and time scales from the entire basin to individual bays in the lake and from days to decades

Figure 7. Harvester machine for skimming AFA off the surface of UKL. An obvious example that not everyone wants to have lower algal concentrations in the lake.

The best way to address a wicked problem is to employ the three principles of adaptive manage that have been described by Norton (2005) (table 5). This approach is suited for complex ecosystem management situations because it demands local evidence and experience to be primary sources of information and puts this into context using multiple scales. Addressing multiple scales forces managers to use a variety of techniques to address those different scales.

Table 5: Three major tenets of adaptive management (Norton 2005)

Experimentalism	emphasize experimental approaches that guide taking actions (including research and management) that will reduce the uncertainty in the future
Multiscalar analysis	use models and approaches that span time and space scales
Place sensitivity	adopt the local place, including natural resource and the people using it, as the perspective from which multiscalar management orients

Hypotheses for control of water quality

There are three active hypotheses that address the control of algal blooms in these two lakes; phosphorus limitation and two versions of the "limno-humic" hypothesis. All of these hypotheses follow from the problem narratives for these lakes (Table 6) which all start with land use changes that include farming and creating levees in the lake. These three narratives were considered in examining the algal response and attempting to devise measurements and/or manipulations that would help us discriminate between these possible mechanisms. An important point is that the underlying hypothesized causes would be operating at different scales and remediation or lake restoration by re-establishing this control would be both at different time and different space scales.

Table 6. Narratives for the problem of too much algae in Upper Klamath Lake and Agency Lake. The three narratives describe how phosphorus, humics blocking light, or humics as inhibitory agents may have controlled the algal population before changes in the basin and lake.

<table>
<tr><th>P control</th><th>Humics – light</th><th>Humics- inhibition</th></tr>
<tr><td colspan="3">land use changes</td></tr>
<tr><td>More non-point sources for P</td><td colspan="2">Less marsh connected to the lake</td></tr>
<tr><td>Increase in external loading</td><td colspan="2">Less humic material into lake</td></tr>
<tr><td>Initial algal growth</td><td>Higher transparency (without humics) allows faster algal growth</td><td>Lower inhibition by humics allows faster algal growth</td></tr>
<tr><td>Positive feedback cycles with internal loading of P from sediments</td><td colspan="2">Colony growth in spring outstrips grazing control by Daphnia</td></tr>
<tr><td colspan="3">uncontrolled AFA growth which leads to blooms and crashes</td></tr>
</table>

Scale of processes and measurements

The processes that we are most interested in for these lakes were the ones that could lead to rapid accumulation of the algae, AFA, or dissipation of a bloom and factors that might vary from year to year. The biological factors are the intrinsic growth rate of AFA, the rate at which these cells can adapt to a set of conditions, photoadaptation over the day that may limit or promote growth, and lake circulation patterns that could form or break-down a bloom through hydrodynamic (rather than biological) mechanisms. The relevant time and space scales for these processes are shown in Figure 8. Figure 8b shows how our experimental approach was to deliberately "bracket" these time and space scales by using a combination of monitoring approaches including: point samples, dataloggers set at one point, weekly measurements from defined sampling stations spread across the lake, transects (see below) and satellite images or aerial photographs. All of these data except for the transects were available through public data sources, however we collaborated with USGS and the Bureau of Reclamation to share data.

We implemented high-resolution transects to collect data that would connect between established monitoring stations, go across gradients that might be shifting and to provide a more synoptic view that could be linked to the satellite information. The data from these transects will be described in detail in another paper (Rueter et al. in preparation). We used a combination of Hydro-Lab and Turner instruments and a GPS that were all connected to a datalogger (Table 7). The response time is an important characteristic of the probes that we selected because we had to move the boat through the water at a set speed in order to get an image of the transect (or to connect multiple transects for a 2-D view).

Table 7. Instrumentation, frequency of sampling and spatial resolution for the high-resolution transects. The boat speed was 1.4 meter per second.

Parameter	**Method**	**Distance (frequency)**
Location	Differentially corrected GPS	1.4 m (1 sec)
in vivo chlorophyll a fluorescence	Turner Designs SCUFA	
Turbidity	Turner Designs SCUFA	
in vivo phycocyanin fluorescence	Turner Designs CYCLOPS - PC	
in vivo CDOM fluorescence	Turner Designs CYCLOPS - CDOM	
Conductivity	Hydrolab Sonde 5	8.4 m (6 sec)
Luminescent DO		
pH		
Temperature		

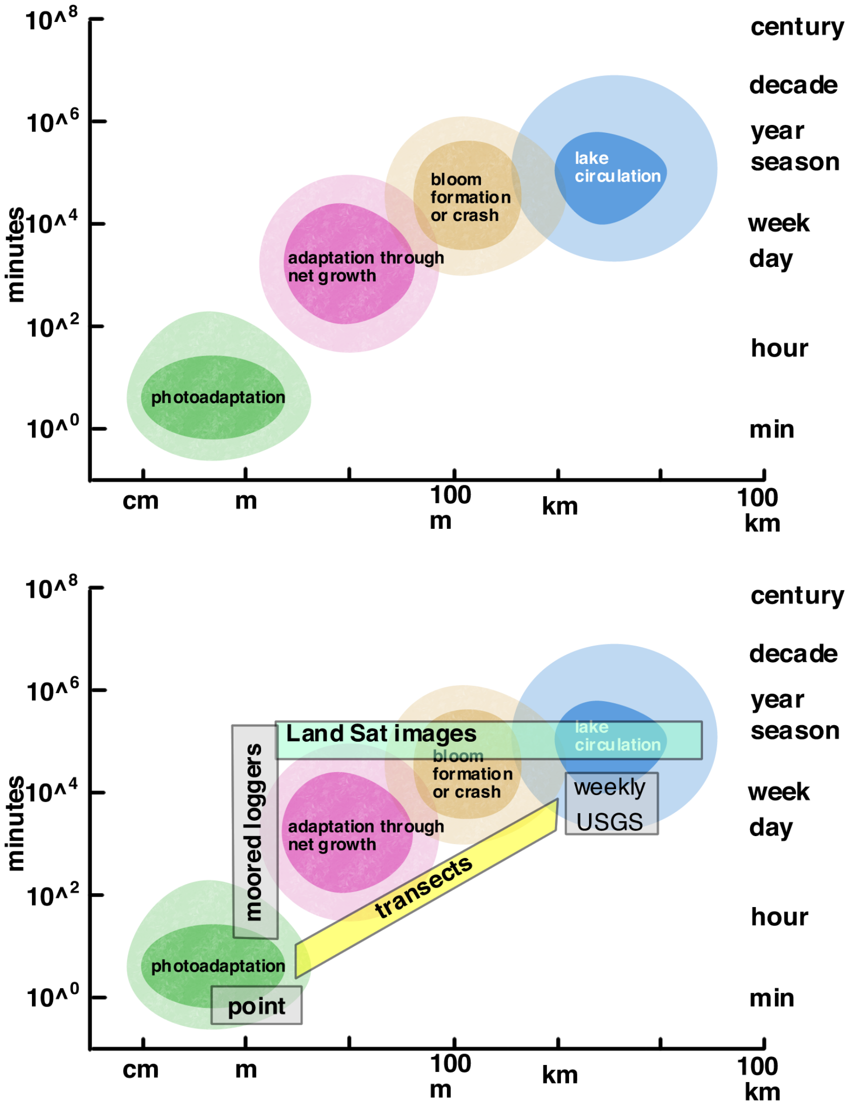


Figure 8. a) Relevant time scales of natural processes in Upper Klamath and Agency Lake. b) Bracketing of these scales with a combination of measurement and monitoring approaches.

Limiting the phosphorus loading to the lake has been estimated to take several decades (as discussed later) and the TMDL process that is used to drive and manage P-reductions applies is being applied to the entire upstream basin. In contrast, although wetlands have been removed from the entire lake, restoration of in-lake or adjacent mashes is taking place on the scales of kilometers of shoreline and areas of 10 to 1000 hectares. These marshes can be re-established on time scales of 5 to 10 years and the impact on water quality could be extremely local (only several hundred meters away from the marsh edge) and during limited times of the year (such as when water is being pushed through the marsh). Thus the current restoration tools work on very different scales.

Example of working across scales

The impact of humic material being introduced to the lake is a good example of the utility of examining the problem over multiple time and space scales. Humic rich water is being pumped into Agency Lake during the summer. This water has been stored in the Agency Lake Ranch behind a levee, and the Bureau of Reclamation pumps it out during a certain window of time. One part of the "limno-humic" hypothesis states that the input of humics should inhibit the growth of AFA and decreases the AFA bloom. In order to assess if this water is having any effect on the lake we have to consider the multiple scales of lake mixing and algal growth.

As an example of the coordinated measurements that can help describe the processes, we conducted transects on the same day as LandSat image and in a zone that overlapped continuous data loggers installed by the Bureau of Reclamation and USGS. The LandSat flies over every 16 days so we had to match our sampling schedule to that. The satellite information, even its raw form shows the variations in the distribution of algae across the surface and, in particular, the clearer zones around the pump input.. The transects help combine the spatial and temporal information.

Chapter 7 – Network Structure and Metrics

7.1 Introduction

The purpose of the "network" view is to look holistically at an environmental problem. In the "systems" view, we broke down the problem into sub-models and expressed those using five icons. In the "network" view we want to learn to describe the behavior of the whole collection of relationships. We also want to be able to predict that behavior from characteristics of the network of processes. The description of these behaviors will require a new and very specific vocabulary.

The "network" view is very useful for systems that have a medium number of objects that interact in very specific ways. We will be using the network view to understand the behavior of food webs; with some questions such as: are they stable? Do they bounce back after a stress event? And, how important are the specificity of the linkages that have developed?

In networks with a small number of objects and processes, the "network" view can easily be made to be congruent to the "systems" view. We will examine a food web (with only a few organisms) from both a "systems" and a "network" view. Even though we can force congruency in these simple network/systems, the goal is to learn to approach more complex networks. A holistic network approach can be very different, and provide very different insight into the problem than a dynamic systems approach. The network view looks at the web of relationships and the systems view tries to describe all objects, flows and controls with a standardized format. The viewer will help us focus on network structures such as loops and metrics as they relate to the general state of the network and its health.

Side Bar: Definitions

- Node - An object or organism that has some relationships to other.
- Links - the relationships between two nodes.
- Connectivity - the degree that the overall network is linked together. (See the calculation of this metric in the text).
- State - the condition of all the nodes and links at any one time.
- Attractor - the concept is that the states of a network will tend toward a particular set of states.
- Resilience - if a network is perturbed enough it may jump to a different structure and behavior. The resilience is how far the network can be pushed and still return to a similar structure and behavior.

Take a small natural meadow as example of how a network and systems view might be different. In the "systems view" we would look at the major flows of energy and nutrients. Our description might cover most flows by focusing on the grasses and a few herbivores. We could learn a lot even if we only looked at energy flows. In contrast, a network model might include all the different species that inhabit the meadow. Some of these might not contribute any significant amount to the gross flows of energy but might help structure the entire ecosystem. For example, fruit-eating birds disperse seeds from many different plant types all across the meadow. The combination of these two views can help us look at energetics or nutrients in one case and focus on biodiversity processes in the other.

7.2 The node and arrow network diagram

The network diagram looks very similar to the systems diagram we used before. There are nodes and connections between the nodes. For example, we might construct a network diagram for a simple 5 species food web (Figure 1).

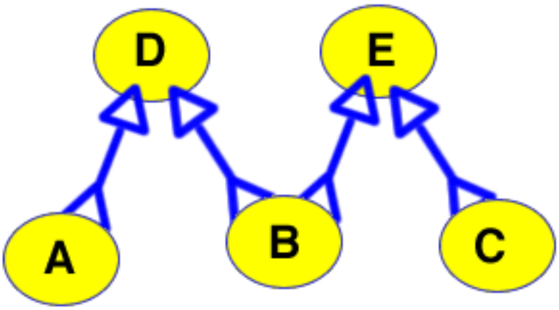


Figure 1. A node and arrow network diagram for a food web with five participants. "A" and "B" can pass energy or materials on to "D". "B" and "C" can pass energy or materials on to "E". The focus in the network view is on the interactions, in this case there are four unique interactions, AD, DB, BE, and EC. The nodes are where these connect. In this diagram all of the connection strengths are the same. For simplicity subsequent figures will show only the lines rather than the arrows, but you should focus your attention on the links, not the nodes.

In this food web, "D" and "E" are the predators and "A"; "B" and "C" are the prey. There is also some competition, for example "D" and "E" compete for "B".

In this network the changes in any one component will have immediate effects and subsequent compensatory responses. For example if the amount of "A" is diminished, there could be an immediate negative effect on "D" which could be compensated if "D" switches to consuming more of "B". The decrease in "B" would effect "E" and that would ripple over to effect "C". Thus a change in one species could affect the entire network. All the species help the network adjust to the initial perturbation.

7.3 Description of network structure

Network structure and function are related. The structure of the food web network is also called the "trophic" structure. The first level of the description is the network diagram, the nodes and arrows as shown in Figure 1. Two important characteristics of this network structure are the connectance and the linkage density. The connectance is the proportion of the number of links to the total links possible. The total number of links possible can be easily calculated from the number of nodes as:

total_possible_links = n*(n-1)/2

Thus the connectance in Figure 1 is (4 links) / (5 nodes*4 nodes/2) = 0.4.

The link density is simply the average number of links per node. In this example that is 4 links/ 5 nodes = 0.8 links/node. This value is very low for natural food webs in part because in our simple diagram there are no links from D and E and no links to A, B and C. Natural food webs can be very complex however even if they only have a link density in the range of 2 links/node.

7.4 Description of network behavior

We are going to focus on attempting to describe the stability of a food web or other network. Stability could broadly be considered the ability of the network to return to its starting condition after a perturbation. Assuming that the food web is in a healthy state to start with, having the appropriate number of connections, it will return to that state after an amount of time.

The ability to tolerate these perturbations is called the "resilience" but it has two different interpretations in the current literature. Some authors use the term "resilience" to indicate the amount of time the network takes to return to its original state whereas others use the term "resilience" to indicate the maximum magnitude of a perturbing stress for which the network will recover. We will be using the second definition in this book. The general sense of resilience is that it indicates the ability of the network to handle stress.

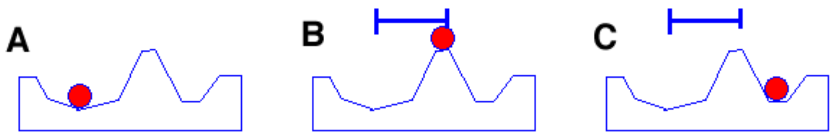


Figure 2. A common metaphor for the resilience of a system. Figure A is the stable state. Figure B shows how far you need to move the ball and yet have it still roll back to its original state. The bar represents the resilience of the left basin (or attractor). Figure C shows that the system was pushed to far and moved to another stable state, different from the original.

7.5 Visualization of a food web network response to a single perturbation

The following food web diagram (Figure 3a) is used to describe the linkages in network that is assumed to be in a stable configuration. Imagine that the links are springs and that the tension of the links is equal. If one of the nodes is pulled a little out of its current position (Figure 3b), there will be an immediate effect on all the springs that are attached to that node and a subsequent, compensatory effect of the entire network to re-establish equal tension (Figure 3c). In this visual/mechanical metaphor for a network, the position of each node in XY space represents how a species deals with its environment. A shift of position of a node should be interpreted as a required change by a species to acclimate to new environmental stresses or conditions. In this metaphor, it is also necessary to envision that the nodes don't move instantaneously, but rather slowly drift toward a new position.

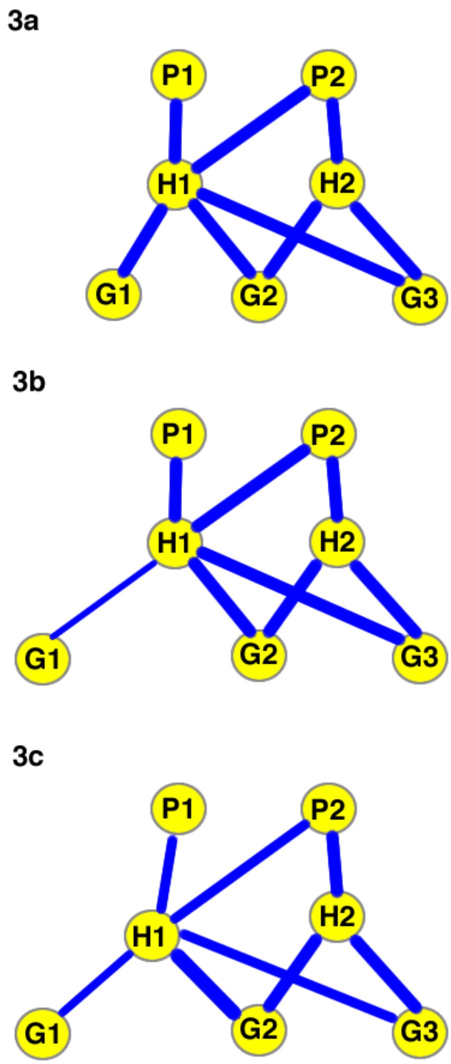


Figure 3. A network that starts in a stable state in which all the links have equal tension (a) until one node is disturbed and the link is stretched (b), followed by compensation by the entire network (c). During the period of compensation, some links are stretched a

little and others may actually be compressed (such as the link between H1 and G2).

If the perturbed node is also allowed to respond, the entire network should return to the same geometry as it started with. If the perturbed node is held in a position for a period of time, the rest of the network may readjust itself to the same geometry but shifted over a bit.

This visualization of network behavior is supposed to give you a feel for how a change in any one of the nodes will lead to a compensation response by the entire network. This view seems to be a cause and effect type system and you can imagine that a systems diagram could also represent it. The visualization of a shifting set of nodes and rearrangement of the links however can be applied to more variable systems that include more parameters than just material and energy flow.

Visualization of the behavior in a network with variable nodes

In the previous diagrams, the position of the node in XY space represented both the environmental condition that the species was dealing with and how it dealt with it. For example, the shift to the left of G1 could represent how a species of grass dealt with a particularly dry spell of weather. What we need to visualize now is what the network behavior would be if the nodes were constantly varying on their own (or being driven by environmental conditions) and what a network of constantly moving nodes and stretching/condensing links would look like. This will be represented below in a series of figures that show how the oscillation in just one node, "G1", would propagate oscillations to other nodes in the network. The oscillation in G1 could be caused by a daily or tidal environmental forcing function for example. In a real food web network, we should expect that several of the species might be responding to environmental conditions and that the network behavior could be described more as a set of dancing nodes than a simple response to a perturbation.

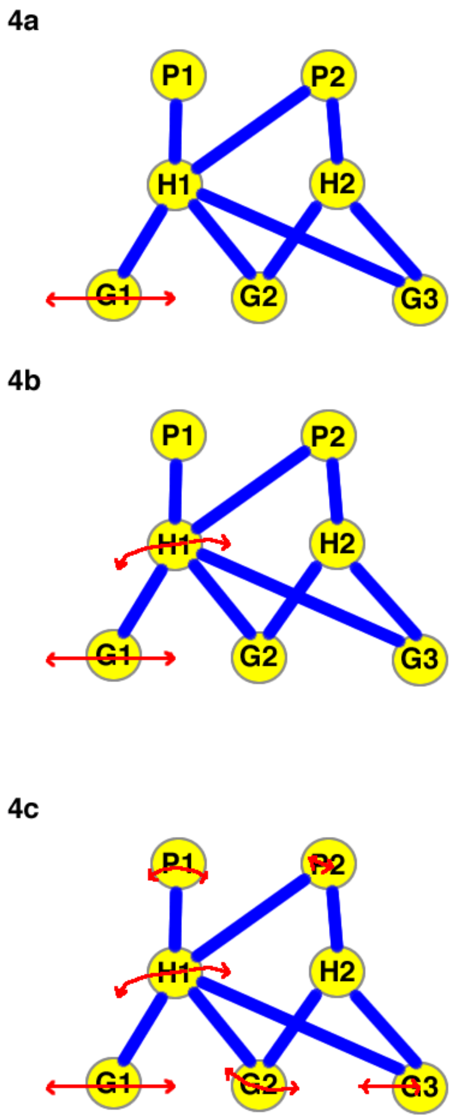


Figure 4. Propagation of an oscillation from G1 to other nodes in the network. Each subsequent diagram shows how the oscillation from the previous diagram might propagate next. As the nodes are

further away from G1, the response can be considerably attenuated.

An important part of this analysis is the number steps that it would take to have the original perturbation propagate through the entire network. In the above example, the next two steps after the perturbation are shown and it would only take one more step to effect all of the nodes. The level of connectivity determines the number of steps.

7.6 Intermediate levels of connectivity

More is not always better in complex and natural systems. If a network has connections between almost all the nodes (Figure 5a), the action at one node has a direct effect on the others and the overall network tends to act like one object. For example a small tree farm where all the trees are the same age and closely packed will act like one stand of trees rather than individual trees. If one gets a disease, it is likely to pass that off to the other trees. If a fire starts anywhere on the farm, it is likely that the whole stand will burn. At the other extreme (Figure 5c), if a network has minimum to no connections it really acts as two separate networks. The action in one part of the network has no way to affect the behavior of the other part. This is often associated with fragmentation of habitats. Each of these sub-networks may also be too small to share perturbations or variations as we saw in the last section. The optimal behavior for ability to share stress and diversity of response is when there is a medium, or intermediate, level of connectedness (Figure 5b).

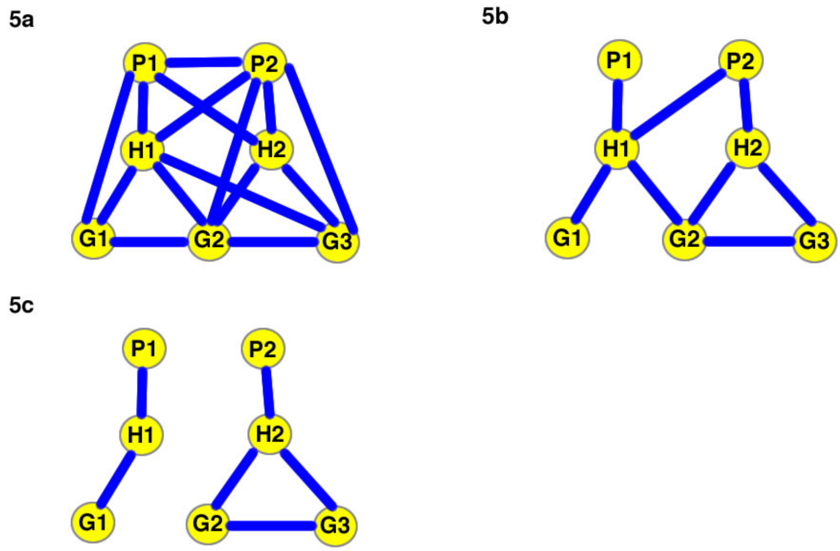


Figure 5 Range of connectivity. A is over-connected or crystalline, B is intermediate and C is under-connected or fragmented.

7.7 Resilience of a food web

The ball and cup metaphor for resilience (Figure 2) illustrates that idea that there are multiple basins of attraction and with enough sloshing around (stress) the ball can end up in the other basin. The amount of stress is the resilience for that particular basin.

Figure 6 illustrates two related network structures that can shift depending on conditions that lead to the health of the top predators. In one case (Figure 6a) Predator 1 is very strong and is able to eat all of the herbivore prey and even some of the plants directly. An example might be conditions that favor a black bear population that can dominate their foraging range and eat plants and many animals. Such a dominant predator will help define the behavior of a food web. The alternate structure is when that predator is not doing well and can only exist by relying on a single prey over a narrow range. The switch allows the competing predator to dominate. This hypothetical example illustrates the concept of resilience. These alternate food webs can flip back and forth depending on the conditions for Predator 1. If the food web is in state "a" but the conditions change enough, then it shifts to state "b". In some cases the two states would be very different and one maybe a health and complex set of interactions and the alternative state maybe degraded or simplified. An example of a switch to alternative stable states is when lakes become polluted. These lakes can shift from having a wide range of algal species, emergent plants and fish in the un-polluted state to a lake with a few dominant algal species and fish that stir up the mud. The diverse state may have a high degree of resilience and able to absorb high amounts of stress (pollution) before it flips to the degraded state, but once it flips, the degraded state may also have strong resilience. Many degraded lakes are extremely difficult to restore to their pre-polluted state even if the sources of pollution are removed. We are interested in preserving the resilience and health of natural and healthy ecosystems in part because it may be so difficult to overcome the resilience of the degraded systems.

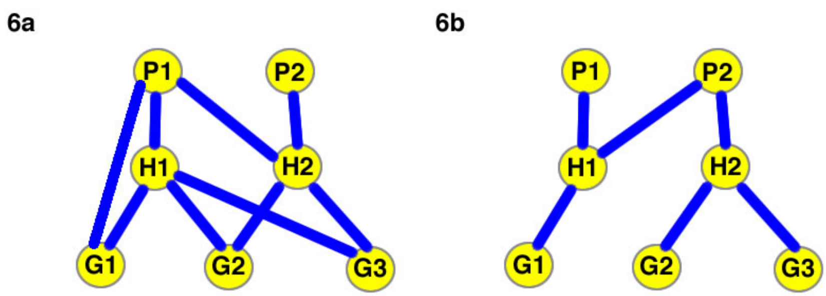


Figure 6. Two related networks that can shift back and forth depending on the health of the top predators. a) Predator P1 is very robust, is able to eat both herbivores (H1 and H2) and has taken on some omnivory (of G1). b) Predator P1 is weak and relies on H1. P2 is able to compete successfully with P2 for H1.

7.8 List of the node and arrow network view of food webs

A food web network has the following characteristics that can be used to understand and describe its behavior:

1. Each link between two species represents specific activities such as predatory prey interactions.

2. Each node should only have several links. More links represent generalist species and fewer links represent specialist species.

3. The food web should have an intermediate level of connectedness.

4. A single perturbation will cause an immediate reaction and then several levels of response from the full network, depending on the connectedness.

5. Continued variability in the environment and the response of individual species can result in a highly complex variation in all of the species all the time. Even though there is continuous or intermediate variability, this can lead to a dynamic yet stable state of the network.

6. Individual perturbations or environmental fluctuations can cause changes in the network that are temporary, with the food web returning to a stable state. If individual or environmental perturbations are too large, the food web network could flip to an entirely different stable state. The amount of perturbation that it takes to just reach the border for a network transition is called the resilience.

7. Healthy natural networks should have a high threshold of resilience.

7.9 Connectivity in spatial networks

In the previous section, we discussed the connectivity of a food web network. The conclusion was that an intermediate level of connectivity is important for stability and resilience of the food web; too much connectivity leads to the entire system acting as a single unit and too little connectivity leads the system susceptible to breaking into separate pieces. In the food web networks that we examined there were usually only several links per node, leading to very low fractional connectivities. Here, we are going to take a network view of region as a lattice of patches that are geographically connected. In this treatment, connectivity is crucial because it keeps the system whole and avoids fragmentation. A loss of connectivity between the small patches leads to smaller and smaller contiguous areas, smaller maximum habitat size within the overall region. Loss of connectivity that leads to fragmentation is bad for the region because it may lead to isolation of sub-populations that are too small to function properly.

Side Bar: Spatial network vocabulary

Lattice - a grid of squares that represents the landscape of an ecosystem.

Maximum habitat size - the biggest area of connected grid elements within the lattice

Fragmented - several to many parts of the lattice are not connected

An overly mechanistic, but motivational, metaphor for the ecosystem region is to imagine that it is an airplane. You are going to ride on this plane, but the ground crew needs to remove a few rivets. You're thinking "certainly the plane can fly safely without one of the thousands of rivets". But each time you fly they take out another rivet. Of course, this metaphorical airline still has first class, but that's another story. When would you stop flying on this airline?

7.10 Fragmentation - how many patches can you disconnect?

We will use a simple model for an ecological region that is a lattice of square patches. Each patch can connect to its four closest neighboring patches. In this model, habitat destruction happens in random patches (rather than along roads or any particular shape). As the individual patches are destroyed, the overall habitat looses connectedness. Continuing destruction of the patches leads to smaller and smaller maximum habitat size, the area of the maximum number of connected patches. Further destruction, in this spatial lattice model, reaches a critical point where the maximum habitat size drops dramatically. Figure 7 shows this general pattern, with an example of the ecosystem region and patches. Figure 8 shows the shape of the curve for largest habitat size.

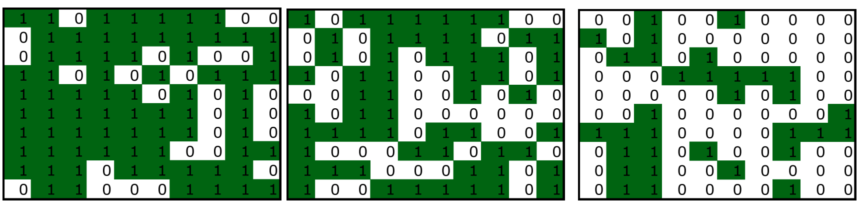


Figure 7. An ecosystem region that is divided up into patches. Each patch is connected to its four nearest neighbors. Different levels of random patch destruction are illustrated, a- minimal (30% loss), b-critical (41% loss), c- overcritical (60% loss). This figure was adapted from Sole and Goodwin 2000.

An important point about this pattern is that as the system reaches a critical level of patch destruction there can be a precipitous drop in the maximum habitat size within that region. This has major implications for management of these reserves and protection from fragmentation. This spatial lattice approach presents a different view of habitat fragmentation than other models. Another model predicts that the largest habitat size would decrease linearly with

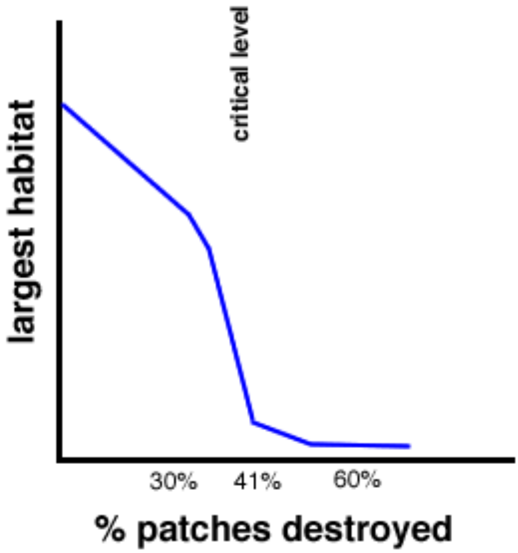


Figure 8. A graph of maximum habitat size against the proportion of patches that have been destroyed. Notice the critical level that is associated with a rapid loss of habitat size.

the % patch destruction reaching a maximum when about 50% of the patches have been destroyed. These two different models would have dramatically different consequences as your approach the critical level. In the linear model, the next patch destroyed will contribute the same degree of loss in habitat as a percent loss at any other level. In the spatial lattice model, a percent loss in critical region could result in an irreversible degradation of the habitat.

Habitat destruction and fragmentation may also result in simplification or impoverishment of food web networks. As the areas get smaller, there may not be the diversity of plants, herbivores and predators to meet all their needs in a variable environment. This can eliminate competitors and decrease the health of the entire system.

7.11 Patch state diversity

In the above treatment we only dealt with patch destruction; removing the patch from the network permanently. Such destruction is obviously detrimental to the larger habitat and species diversity that can be maintained. Diversity of the successional state of a patch and variation in the level of connectedness between patches can create dynamic situations that foster biological diversity. A mosaic of habitat, microclimates and communities with multitudes of transitions between them is a very rich environment.

The metaphor/example for a habitat mosaic is the forest that is kept in a dynamic state by the continual, but intermediate level, of natural disturbances. For example, you might observe the following states of patches within the “forest”:

Bare ground following a fire
Grasses and other pioneer species
Tree seedlings
Immature deciduous trees
Deciduous trees
Coniferous trees

There are a multitude of small disturbances including localized fires, blow downs, river course changes, and other events. These events don't propagate across the entire landscape because of the terrain and because previous small disturbances have yet to finish playing out. For example, a patch of forest only burns up to the border of a recent fire. Intermediate disturbances such as these can lead to higher biodiversity and a healthier and resilient ecosystem.

7.12 List of spatial behaviors

Destruction of patches will decrease the largest habitat size within an ecoregion.

There is a critical level of patch destruction that leads to a precipitous drop in the habitat size.

Patch disturbance, rather than destruction, at an intermediate level can lead to increased biodiversity in the region.

7.13 Case Study:Biodiversity and stability of natural grasslands

There are many reasons to conserve biodiversity ranging from a moral obligation to protect the Earth's resources to more pragmatic and utilitarian reasons that serve humans. The issue of preserving biodiversity has usually been framed in the context of saving individual species, especially threatened or endangered species, before they become extinct. Another view of saving biodiversity is to save or restore communities that provide essential ecosystem services for humans.

One crucial question is whether more complex communities perform better than simple communities. This question has two important parts; what do we mean by "simple" and "complex" and what do we use as a basis to judge what is "better"? For our purposes the complexity of a food web will be related to the number of species and the connectivity. The complexity of these systems will increase with the more ways that the species can interact. More complex systems will also have an intermediate level of connectivity, every species will be connected to several other species. Better performance does not mean simply more efficient production. In natural communities, better performance is related to the ability of the entire community to survive disturbances. A "better" community structure would bounce back from small disturbances very quickly and would have to be very severely disturbed not to recover. The degree of the stress that a community can withstand and still recover is the resilience.

Researchers have taken several approaches to address the relationship between species richness and the productivity of community. One approach is to construct artificial communities in well-controlled experimental chambers and another approach is to compare natural communities that have different species richness. Each approach has its benefits and drawbacks.

In a study conducted in artificial and highly controlled chambers, communities with nine, fifteen and thirty-one species were compared. All three communities consisted of decomposers, primary producers, primary and secondary consumers. The results were that the productivity (measured as total plant biomass increase over time) was higher with more diversity. The most diverse community had almost twice as much production as the species-poor community. The species-poor community was also more variable, indicating that it was not as stable as the more diverse communities.

Another study conducted in the field demonstrated that species-rich plots of grassland were more resistant to drought events than species-poor plots. These species-plots were both more resistance to drought and they recovered more rapidly after drought stress. More diversity seemed to help the communities use the resources more effectively and thus increase both productivity and resilience.

We have to be cautious when interpreting these studies and attempting to extrapolate from controlled and small-scale experiments to the ecosystem level. There are many methodological and statistical problems that could weaken the impact of these findings. These studies, however, are an important demonstration of the value of diverse communities. The more complex networks in diverse communities are able to utilize the available resources in flexible ways that can lead to their ability to resist stress in the first place and recover more swiftly afterwards.

A more complete story

Please see these references for a more complete description of this problem.

Chapin et al. (1998). Ecosystem consequences of changing biodiversity. Bioscience ???:45 - ??/ (January)

Tilman, David & John A. Downing. 1994. Biodiversity and stability in grasslands. Nature 367: 363-365. (27 Jan)

Tilman, David, Peter B. Reich, & Johannes M. H. Knops (2006) Biodiversity and ecosystem stability in a decade-long grassland experiment. Nature 441:629-632 (June 1)

Tilman, David, David Wedin & Johannes Knops. 1996. Productivity and sustainability influenced by biodiversity in grassland ecosystems. Nature 379:718-720. (22 Feb)

Or you can search for "drought", "biodiversity", and "grasslands" to find other references.

Salient features

The focus of this case study makes it ideal to examine some of the points from a network perspective. The proposed reasons for increased stability of the diverse grassland include compensatory interactions between species. The weak positive and negative influences that these species have on each other can be described as linkages (rather than flows and stocks that we would have to use with our simple system viewer). Another feature is that they are looking for resilience and stability under conditions of disturbance or perturbations by the weather (i.e. drought).

to be added: a list and simple description of the species-species interactions and microhabitat-species interactions that were observed.

7.14 Summary

We can describe the structure of ecosystems or other functional networks and use metrics (such as link density or connectivity) to examine the function. Some networks, such as food webs, can be represented with node and link diagrams and others, such as forest surface cover, can be better represented with a lattice and fixed squares. In both types of representations, the concept of "intermediate level of connectivity" is important relative the health and resilience.

Multiple Perspectives V4.2

Chapter 8 - Risk, Uncertainty, and Indeterminacy

The only thing that makes life possible is permanent, intolerable uncertainty, not knowing what comes next.
- Ursula K. LeGuin

8.1 Introduction

Generally, science makes predictions about how a system will behave and then tests these predictions in a rigorous manner. In environmental science we focus on making testable predictions about the real environment we live in. Even if we are studying the outcomes of experiments with test tubes or isolated microcosms, the purpose of this work is to understand the processes so that we can either react to or control the future of our environment. The real world (as opposed to experimental systems) is full of uncertainties caused by all possible types of interacting factors. Thus, environmental science, working in the real world, must deal with uncertainty as part of our everyday work.

This chapter describes the limits on our ability to predict the future and what that means for environmental science. The important message is that we can't always just study a problem or gather more information to make a better decision. There are cases when we will not be able to know the possible outcomes with any degree of certainty. There are even situations where our own actions create so many more potential outcomes that we might actually know relatively less after we start solving the problem. For example, if there is an outbreak of a disease carried by mosquitoes we might have to spray, but after we finish spraying the impact of the insecticide and the change in the ecosystem are impossible to predict. As a general rule, the bigger the project or the higher the energy density (kWatts/m^2), the more indeterminate the system becomes. Stated in another way, the harder we try - the more possible outcomes we open up for the future.

It is important to differentiate between three different types of unknowns.

Risk - a probabilistic estimate of how likely an event or exposure will be

> If we can calculate the risk and the potential damage from exposure, then we can calculate the amount of money or effort we should expend to control that risk.

Uncertainty - a broad range of possible outcomes and complexity makes it impossible to define a set of probabilities.

> We can create and use scenarios to describe the different paths that may happen in the future, but we have no way of knowing which path society will take.

Indeterminacy - there is some information that we will not be able to know

> Some times our actions actually increase the indeterminacy because as we focus our energy and mobilize resources to address a problem, we create a fundamentally bigger set of outcomes (Adams 1988). This larger set may include "surprises" which are qualitatively different outcomes that are unexpected.

8.2 Method for examining uncertainty and risk

The method outlined here is to start by scanning what you know about the problem with a checklist. The scan will look for what we think we know and can learn easily compared to the information that may be difficult or even impossible to get. The second step is to describe the problem in terms of bounded rationality. The third step is to describe the structure of the information that is available. The fourth step is to bring in values and cultural interpretations of the problem. Finally, the fifth step is to create imaginative narratives for about what might happen in the future. These scenarios might illuminate qualitative change in the outcome and surprises?

We should evaluate our actions by assessing the level of our understanding in the following levels:

- what we know
- what we expect we can learn
- what we can't or might never know
- what are we doing that might create "surprises"

A "surprise" is a change in the system that is qualitatively different than we were expecting. For example, if we over fish a region, instead of getting just less fish we are surprised when we get a sea filled with jellyfish. The ecosystem has flipped to an entirely different food web dynamics.

The degree of proof or confidence we need to be able to take action is related to our worldviews (see Chapter 11: Values and Worldviews). In particular, the precautionary principle states that if we are uncertain we should decide to take the path that leads to the least potential damage. Some worldviews embrace the precautionary principle as a standard of proof where as others believe that progress in general will be of a benefit and there are tradeoffs that have to be made to sustain growth. For example, the set of values we called the "committed environmentalists" believe that we need to be more humble about our scientific and technical abilities whereas "cornucopian" believe in the ability of scientific advancements to solve emerging problems.

Defining the limits to our understanding - Bounded rationality

Counter to many people's belief, there is a limit to what we can know about a problem and how much of that knowledge we can apply. This means that any decision that we make can only rationally consider a limited number of options, i.e. our ability is bounded. If we had instantaneous information gathering and all the money we needed, we might be able to claim unbounded rationality.

The cost (in dollars and human effort) required to collect information is a very pragmatic consideration. Given that environmental science is focused on solving problems, it wouldn't make much sense to spend more money investigating a topic than to simply solve the problem. For example, is it reasonable for a wildlife agency to spend a couple hundred thousand dollars to determine if a wetland has threatened or endangered species or should they just buy the property or put it into a conservation easement program? A similar concept is that in many cases it is best to take environmental management actions (such as preservation or remediation efforts) that are designed to be experiments. Combining required management actions with scientific monitoring is one of the tenets of "scientific adaptive management" and is as much a result of bounded rationality as limited funds.

Structure of environmental information

For many environmental problems the problem of bounded rationality is exacerbated by three related characteristics of the structure of the environment. First, the physical environment is made up of individual places each with unique characteristics and histories. Although we maybe able to collect, enter and manipulated data with geographic information systems, but there is still a unique set of characteristics and history for every location on the planet that must be considered. Second, because of this spatial nature, environmental data is time-consuming and expensive to collect. There are proxy measurements (related and standing in for the parameter of interest) that might be made from satellites or other remote sensing devices, but these are always suspect and take a lot of information to establish the value of the proxy in the first place. Some crucial information in species conservation, for example, requires that individual elephants, whales, warblers or other animals are tracked and counted. There are many examples in environmental ecology where specific sites have to be studied. Third, processes take place at different scales. A collection of data taken at a small scale does not automatically aggregate to describe the process at a larger scale and an average measurement at larger scales may miss critical processes that happen at smaller scales.

The average slope and soil wetness of a hillside doesn't predict a landslide. A small section of steep and saturated soil can precipitate a landslide that is much larger in extent. Thus the uniqueness of spatial or individuals, difficulty of collecting place-specific information and the problem of scale-discontinuity of processes require that we need to learn to make good decisions with limited information, learn from those decisions and continue on.

8.3 Cultural and worldview perspectives on risk

The perception and response to environmental risks has a strong cultural context (Douglas & Wildavsky 1982). Making and decision about the future, such as the impact of population or climate change, is essentially the process of dealing with risk and uncertainty. Different world-view groups deal with risk differently. For example Douglas and Wildavsky (1982) list four main types of risk (Table 9.1) and claim that the some worldviews worry about some of these more than others. For example "individualistic" people would worry about the collapse of the market and loss of capitalism as a driving force for change. Hierarchists abhor situations where the rules and regulations are incomplete or ineffective. Egalitarians are worried about general effects such as waste and pollution that aren't controlled effectively by general agreement and may take strict laws or other governmental action. These actions erode the spirit of cooperation for the common good.

Table 8.1 Worldviews and risk emphasis. See chapter 11 for more description on worldviews.

four main risks	world view that worries about this most
economic collapse	"individualistic"
foreign affairs	"hierarchists"
pollution	"egalitarians"

crime	"hierarchists"

Differential sensitivity to risk also means that there is no generally agreed upon definition of acceptable risk. Egalitarians would rate the risk of pollution much higher than the other world-views. Continual dialog is required to negotiate the level of risk that a community is willing to accept. This reinforces the dilemma in wicked problems where members of the same community who may have different world-views will not agree on a single or unifying scientific definition of environmental risk. Proposed alternative solutions should be judged against all four-value systems. In these situations, one of the best approaches is to explore the problem from many perspectives and workout how the different groups would view the risks of the problem and proposed solution differently.

Anticipating surprises by using imaginative scenarios

A good way to address wicked problems is to use our imagination to create a set of scenarios for the future that are contradictory, i.e. they describe plausible future conditions that are different. These scenarios might be limited to a description of a watershed, city or the entire planet. For example, a set of scenarios was developed by the Millennium Ecosystem Assessment Project (Millennium Ecosystem Assessment 2005).

Table 8-2: MEA Scenarios

SCENARIO	A FEW FEATURES
Techno-Garden	high performance agriculture innovation and market rewards
Global Orchestration	policy driven effective global governance
Adapting Mosaic	regional solutions

	continued social experimentation
Fortress World	wealthy protect their resources inequitable resource allocation

Both the construction and analysis of the set of scenarios will help deal with uncertainty. We have to have scientific, technical, economic and social expertise to construct feasible scenarios, but that is not enough. As Einstein said (check quote)

> "While knowledge defines all we currently know and understand, imagination points to all we might yet discover and create" Albert Einstein ****

This approach helps us deal with surprises by broadening expectations and "expanding the diversity of futures people consider" (Lempert 2007). But creating a wide range of possible options increases uncertainty and people may be very uncomfortable dealing with the ambiguity of their personal future. This "multiplicity of frameworks, perspectives, and experiences if needed" helps us anticipate surprises because we are more likely to have considered a scenario that contains some hint of qualitative changes that could occur. Sometimes we refer to these surprises as crossing a "tipping point" or "threshold". Scenarios can also help identify if a society is near a tipping point that could be altered and create a dramatically different future path (Lempert 2007).

In the spirit of the scientific method, when we study these options we are looking for ambiguity and paradox (Brown, Deane, Harris & Russell 2010), points that don't quite make sense to us, and should be checked. We are not looking for which scenario fits with and reinforces our own personal worldview. "Poorly structured, ill defined, difficult-to-grasp problems can be solved. They are not intractable. They just require novel thinking and approaches." (pg 97 - Schwartz and Randall, 2007). In scenario thinking, the most important advice is not to use a single approach (Schwartz and Randall, 2007).

We are in a bind. The lessons learned from environmental science are that we have to be cautious about actions we take, but the pressing nature of the problem means that we have to be bold (Lempert 2007). The exercise of crafting scenarios can engage more people from different backgrounds and lead to creative ideas for what the future might look like and how to get there. The fact that these scenarios are feasible and possible accentuates how the future is uncertain but that it is up to us to deal with that uncertainty and intentionally create the future that we want. If we resign ourselves to a juggernaut of globalization (Giddens 2003) or continuing environmental degradation we are being fatalistic rather than being agents in constructing our society.

8.4 Conclusions

Much of this chapter has dealt with the challenges of dealing with uncertainty and risk. My emphasis on these warnings about the difficulties is a reminder that we need to be humble and cautious as we propose solutions. Environmental science is generally an optimistic undertaking. We believe that it will be worth our attention and effort to improve and protect our environment.

The simple scan method provided here (assessing what we know and don't know) is a starting point for analyzing the information needed to support good decisions. If decisions and actions need to be taken with imperfect information and uncertainty, then we need to use an adaptive management strategy so that our management actions decrease the uncertainty for subsequent efforts.

PART 3: PRELIMINARY STEPS THAT CAN SET UP BETTER DECISIONS

Which way should I go?

Chapter 9 - Games View of Decisions

The studies of strategic interactions between multiple participants have lead to some operational rules that are often called "game theory". This approach divides a decision-making problem into possible choices that you can make. These are matched by decisions that your opponent or other players make. Your strategies may be "pure", in that you always follow one set of rules (strategy) to make each decision, or they might be "mixed" in that you randomly choose one strategy or the other. Similarly, the payout from each interaction may be a pre-determined number or you may only know a probability of a particular outcome. In this introduction to game theory, we will only use "pure" games in which you select from a list of strategies. The first approach will be to play the game against another player who has the same set of choices that you do. In the second example, we will modify the game to play "against nature", in which the final outcomes are determined by the strategy that you choose and different environmental scenarios.

9.1 Simple game set up

The simplest game is when you have two choices, your opponent has the same two choices and you each have to commit to a strategy without knowing what the other is doing. A trivial example of this set up is given in Table 1. You have to tradeoff the enjoyment of wearing your favorite shirt versus the risk will look like a copycat. The relative values for the possible outcomes would determine what you would choose. This is called a dilemma because no choice is optimal all the time.

Table 9.1. A simple game for what to wear to the party. Your choices are limited to the choices in the first column. Your friend chooses independent of you. The outcome of your coolness is given in the table.

	Your friend - wears the same shirt	Your friend - doesn't wear the shirt
You - wear your favorite shirt	You both look like copycats	You look cool, he doesn't
You - don't wear your favorite shirt	He looks cool, you don't	Neither of you look cool or dorky

In the shirt example, if you choose not to wear your shirt, this would be an example of a strategy that limits your negative outcome by choosing the strategy that steers you away from a very bad outcome. It doesn't necessarily provide you with the best outcome. We will call this strategy "avoid the worst".

9.2 Use of a common pool resource as a game

Another familiar example of this game is the "Tragedy of the Commons" scenario. The commons is a "common pool resource" in that you have no control over who uses it but anyone who uses it decreases its usefulness to others. You have a choice of grazing your sheep on the commons either early or at the approved time. The approved time has been determined by cooperation between you and your neighbor and would allow both of you to graze 10 sheep all season. Your neighbor also has the same choices. You have no control of what your neighbor does and you don't know what he will do. The strategies and outcome matrix is given in Table 9.2.

Table 9.2: The tragedy of the commons expressed as a pure strategy game. The outcomes for each player are expressed both by rank and with values; best =11, good =10, poor=0,and worst = -1. Early grazing gets you more money but wrecks the pasture.

	Your neighbor - grazes early	Your neighbor - grazes at approved time
You - graze early	You both do poorly.	Best for you, worst for neighbor
You - graze at approved time	Worst for you, best for neighbor	Good for both of you

The game outcomes show that if you cooperate with the approved time, you could very likely have the worst outcome, especially since this is the best option for your neighbor. If you choose to defect from the rules and graze early, the worst possible outcome is "poor" rather than "worst", but there is a chance you can have your "best" outcome. Your rational choice is the non-cooperative strategy, which is to graze early.

This game illustrates the dilemma of cooperation in the commons in a different way than simply listing the utilities. It shows that if you both choose the non-cooperative strategy, you will both have suboptimal outcomes.

The obvious solution is to agree to cooperate. However, if you are allowed the option to talk to your neighbor and reach an agreement then that is a different game for two reasons. These are not trivial or picky points, they are very important conditions to understand. The first reason is that, in a common pool resource such as this pasture, you don't control who comes in and when they graze. If you and your neighbor agree, there is nothing to keep another neighbor from grazing there early. As long as it is a common pool resource, you always have the possibility that there is another "neighbor" who can show up unannounced. The second point is that even if you made an agreement with your neighbor over the fence, there are no rules that state what you would do if he broke the agreement. You could agree to cooperate, then he could break the agreement, graze early and guarantee the best outcome for himself.

Some commons are governed by rules that account for monitoring compliance and penalties for infractions. These rules need to be enforceable at a reasonable price otherwise it defeats the purpose of sharing the commons. In contrast to the impression in many of the environmental science texts, the tragedy of the commons is avoidable (i.e. it's not really a tragedy). There are many societies that govern common fisheries, pastures, woodlots and water rights very effectively. Before we jump to conclusions about the inevitability of sub-optimal outcomes in governing common pool resources or that all common pool resources need to be converted into private properties, we should understand how to establish and tend for institutions that favor.

9.3 Playing the game against nature and the "Precautionary Principle"

Using the same type of outcomes matrix, we can define a set of choices for you and a set of outcomes that depend on factors out of human control. This is called a game against nature. This framework is very valuable even if you don't know the risk (or probabilities) associated with each of the possible natural events. Table 9-3 shows a simple game against nature.

There is no way to account for what some individuals might do, but the rational choice in this situation is to take the "avoid the worst" strategy and avoid the costly damage. In environmental science, this is called the "Precautionary Principle". The principle is that if you don't know the probability of the outcomes, you should adopt a strategy that minimizes the potential harm. This principle is applied to our use of pesticides and other environmental interventions.

Table 9-3. Strategies for dealing with a possible tornado. You don't know the probability that a tornado will touch down on your street.

	No tornado comes down your street	Tornado comes right down your street
You - spend money to prepare for a bad tornado	You "wasted" your money	You suffered only minor damage and lived through the storm
You - spend the money on a new TV	You didn't waste your money and you have a cool TV in front of your lounger	Your house is wrecked and it isn't the same watching your TV from a folding chair

We are playing a similar game against nature when we respond to the threat of global warming and climate change. We can identify several strategies that we could take and we can estimate the potential outcome for different warming scenarios. The structure of the game and the favored strategy is similar to Table 9-3, take the strategy that avoids the worst possible outcome.

Although the outcomes in Table 9-4 are a bit facetious, the point is that if you take precautions in the face of uncertainty, there is that possibility that this money will be wasted. The opportunity for our society now is to look at this game and change the rules such that we invest in infrastructure and environmental protections that we want anyway, but that will protect or mitigate the effects of climate change. We should be looking for strategies to change the nature of the choices so that we can find win-win solutions. For example, maybe we can find strategies that both save energy costs and reduce the threat of global warming.

Table 9-4. Global warming as a game and using the Precautionary Principle, i.e. "avoid the worst" strategy.

	Turns out, no global warming	Global warming hits hard
You - spend money to prepare for global warming	You "wasted" your money	You suffered only minor damage
You - spend the money on more highways	You didn't waste your money and now you have even bigger highways with ocean views	Your life is wrecked and you need all the highways in NY are under water

9.4 Summary

The "games" framework is very useful for evaluating different strategies and making decisions. Two examples of how this framework is related to classic environmental problems are presented; the tragedy of the commons and the precautionary principle. Both of these simple games show the benefit for players choosing the strategy that avoids the worst possible outcome.

9.5 Case Study: Fisheries as a common resource

Fisheries in the open ocean are just one example of a common pool resource that can be exploited by anyone or any country. These systems are sensitive to over exploitation. Common pool resources are situations that have high subtractability (any use subtracts the resource from any other use) and where exclusion from the resource is difficult (anyone can gain entry). There are other classifications of resources that would have different problems and appropriate solutions.

Table 9-5: Resource classification by subtractability and exclusion. Subtractability means that a use of one unit of the resource removes that unit from anyone else's use. Exclusion is whether it is easy to limit access or impossible.

	low subtractability	**high subtractability**
difficult exclusion	public goods	common pool resources
easy exclusion	toll goods	private goods

Maximum sustainable yield and over harvest. The amount of fish that is taken in any season is the "yield". Ecosystem managers calculate the maximum sustainable yield (MSY) as the maximum value of the population times the growth rate. (Ecosystem managers actually use much more sophisticated models than the “maximum sustainable yield” but these models have essentially the same features, i.e. estimation of a population growth under conditions of high natural variability.) At low population size the number of reproducing fish limits the yield. At high populations the yield is limited by the decrease in the growth rate from inter- and intra-specific competition for resources. The maximum sustainable yield is the theoretical maximum point that is half of the carrying capacity. Over harvest can happen in two ways, either the maximum yield is an overestimate or a correct MSY could be taken too early when the population is still too small. Over harvest decreases that population such that the growth for the next season will be decreased. Thus, over harvest and early-harvest are related processes.

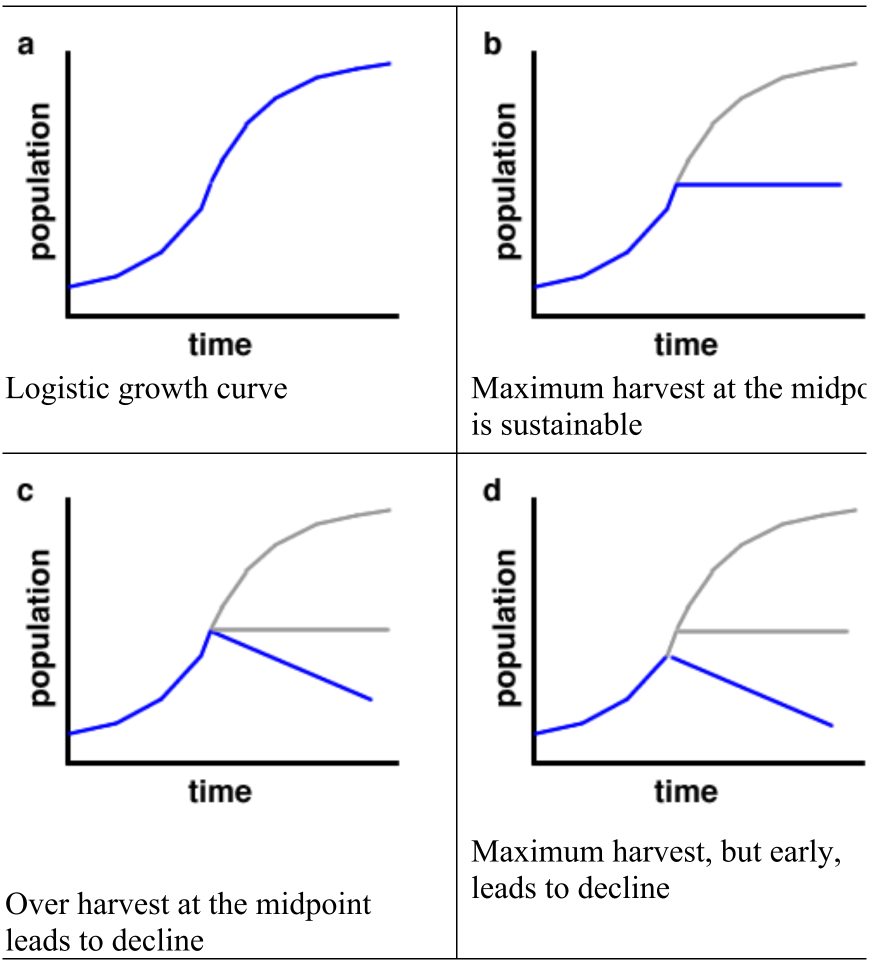


Figure 9-1 Theoretical optimal sustainable yield for a population going through a logistic growth transition. Early in the growth

phase, rapid growth rate and the number of fish control the population growth. Later, the population growth (yield) is dominated the decrease in the intrinsic growth rate as the population reaches the carrying capacity. The middle of the curve (the area with the steepest slope) has the population value that will give the highest yield. b - when the maximum sustainable yield is initiated just as the population gets to the midpoint, the population will stay constant. c- if the harvest is higher than the maximum sustainable yield, the population will decrease. d- Applying the maximum harvesting rate before the population has reached the mid-point will also result in a decrease in the population.

Actual harvest rates should be below this theoretical maximum yield for several reasons. First, the process of harvesting can degrade the conditions necessary for optimal growth. Too many roads in the forest, catching too many non-target fish or trampling of a pasture are examples of this type of damage. It reduces the ability of the environment to grow the resource without directly showing up in the harvest. Second, natural variability in the conditions should also be accounted for in calculating the actually yield that can be tolerated. Variations in weather or other populations in the ecosystem can result in good and bad seasons for growth. Maximal harvesting during a bad year can decrease the population below the sustainable level. Often the variability is a source of uncertainty for ecosystem managers. Still, managers need to be able to make decisions to set a harvest rate and to be take precautions against the collapse of the fishery.

Variability in fishery production. Even healthy natural environments undergo swings in the overall productivity and especially the growth of one species in the food web. Understanding that this variability was a key component of our attempt to understand food webs using a network view (see Chapter 7). The degree of variability can be quite large even in healthy populations. However, with artificially harvest superimposed on top of natural variability, the results can be disastrous. The following simulations (Figure 9-2) demonstrate the effects of a population that is either fished, or perturbed by a density dependent loss, or both. Each simulation run represents one possible trajectory through time, with random events. There is a range of outcomes, and each can be predicted roughly from the probability of the loss (Figure 9-3). Given the dynamic nature of natural ecosystems, it may not be possible to determine the probability of loss to any degree of certainty, i.e. the loss may be uncertain no matter how much this population were studied.

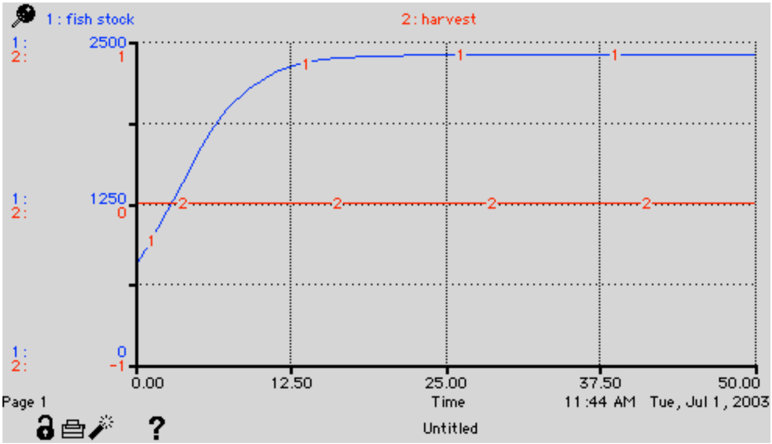


fig9-2a - no harvest

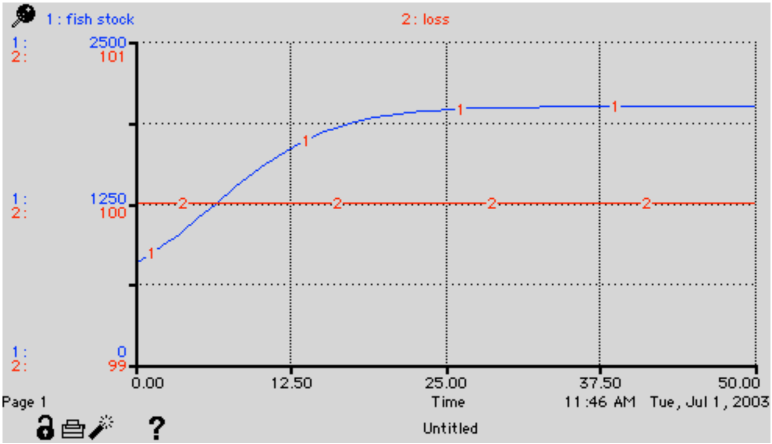


fig9-2b - harvest rate of 100

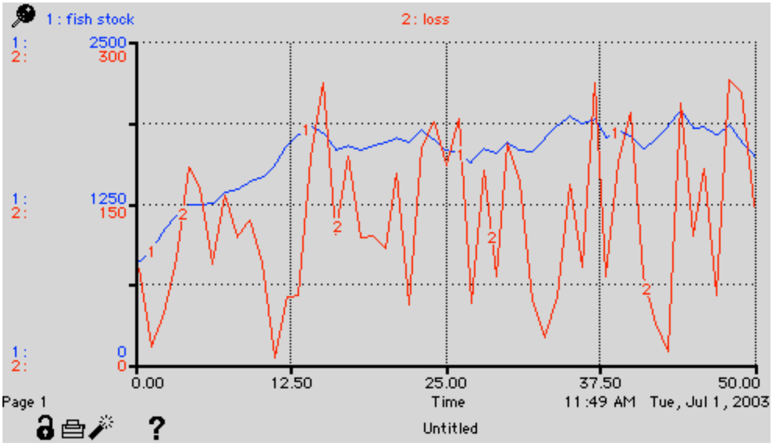


fig9-2c - one example run with a stochastic loss of up to 10% of the population per time

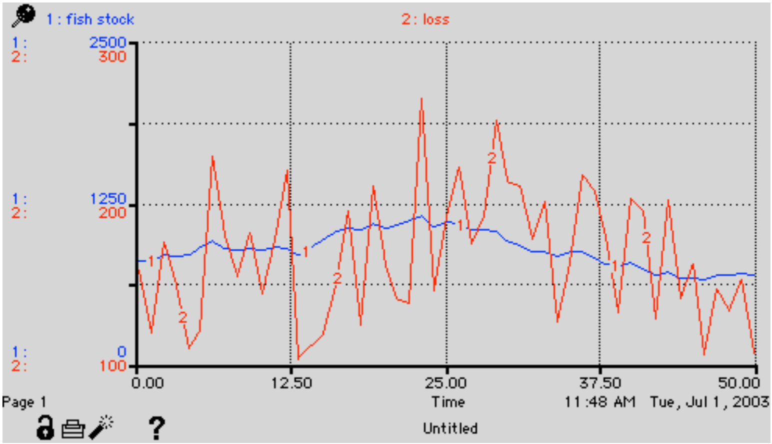


fig9-2d - another example run with both a constant harvest of 100 and a stochastic loss of up to 10% of the population per time.

Figure 9-2. Simulation results for a fish stock that is growing with and with harvest and stochastic loss terms. The parameters for all models are r=.3, K=2400, initial population =800. The population is controlled by the logistic equation. The stochastic loss is a random percent loss (up to the maximum of a 10% loss) times the population. a- growth with no fishing. b - growth with a harvest of 100. c. stochastic loss only. d- harvest and up to a 10% stochastic loss combined.

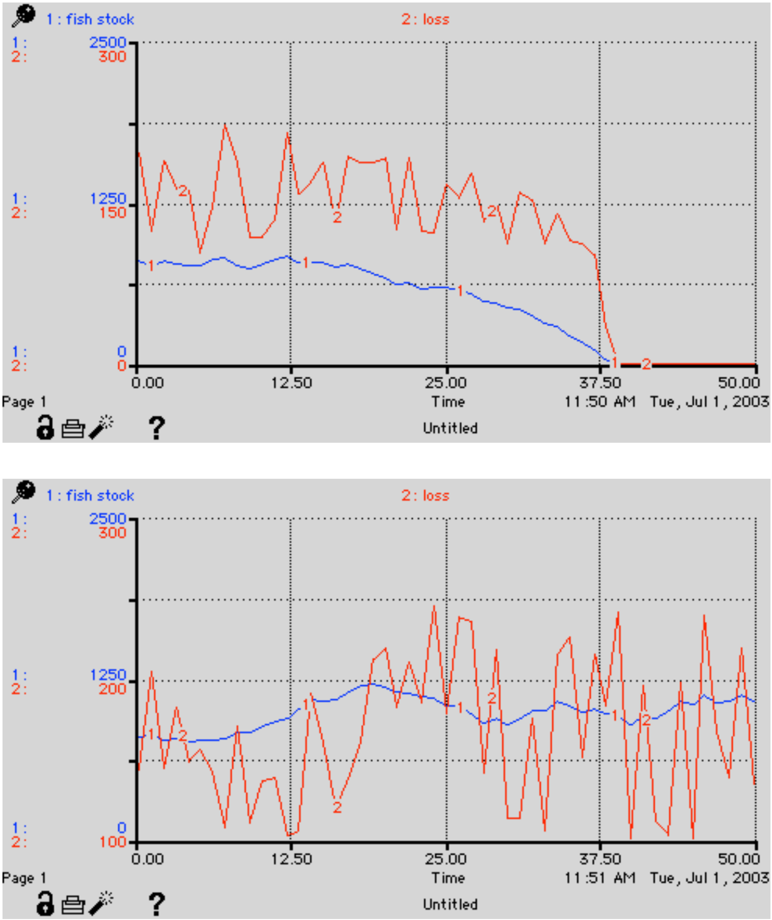


Figure 9-3. With any stochastic loss there are multiple trajectories for the population. a - one selected output that shows a collapse of the population. b - another selected output that shows increase in the population over the period shown

There are many ways to cause extinction. Just as it was claimed that "all roads lead to Rome", it seems that for our current civilization, all roads lie perilously close to causing extinction and collapse of our natural resources. Our choice to exploit natural resources must be accompanied with taking responsibility for our actions and the consequences for the environment.

Our society faces two fundamental decisions when we use of natural resources. First, if the resource is a "common pool resource", we have to decide how we will adjust our use to that of other users. How will we know if we are overexploiting the resource? The second question we face is how to deal with the uncertainty in the system and whether to make decisions based on "precautionary principle" (which states that in the face of uncertainty, choose the path that will do the least damage).

9.6 Summary

The case study demonstrated the process of using a game matrix set up can to help simplify the first steps in making a decision. This involves making a grid and filling out three different types of information. First, list the choices that you are faced with. Second, identify the major possible scenarios for environmental conditions. Third, describe the consequences of each possible combination of choice of action and environmental condition. Analysis of this grid can help you determine if you might want to make a decisions based on avoiding the worst-case outcome if that is particularly bad, or it might show you that there are some other strategies that could help reduce your costs and risks.

Chapter 10: Environmental Accounting

Outline and notes

Note: I appreciate the assistance from Darrell Brown but take full responsibility for all errors in this chapter.

10.1 Introduction

Many discussions about environmental issues are framed in a way that emphasizes how we (as individuals, communities or countries) would be better stewards of the environment if we considered all the costs associated with environmental damage. We often hear that we need to account for the "true" or "full" costs when we make a decision. There are two major assumptions in this statement. The first is that if we could see all of the costs, we would make the rational decision that would be best for both our immediate and long-range future. Whether humans are able to make decisions based simply on their own rational judgment of the overall benefits is a very interesting debate in history, sociology, political science, economics and religion. We won't be able to resolve that here. The second assumption (implication really) is that there is available information on the "true" or "full" costs and that we are ignoring or failing to use that information. This chapter will address the value of attempting to account for more than the immediate financial costs of human activities. We will ask what information will we need to take into account all of the effects AND what systems will we have to implement to make decisions based on this information.

This chapter presents a framework for accounting for the impact of events and how we will observe, process and make decisions. This is complicated by the fact that environmental impacts effect multiple aspects of the system (financial, biological, social just as a start) on a range of time and space scales. The purpose of this is to have you thinking about the entire framework as "accounting" and not just the collection of data.

10.2 Economics vs. Accounting

Economics is a powerful discipline that uses tools for analysis of human behavior and markets. There is a wide range of sub-disciplines for Economics that are useful to scientific environmental management. Environmental economics addresses the following issues with appropriate assumptions and at appropriate scales:

- human preferences and tradeoffs
- values of resources
- processes and activities can be monitorized

Accounting practices are more focused on setting up a system that will collect information required to make a specific type of decision. The procedure would include:

- decide what to measure, track that, and make decisions
- supports business approach (need to measure)
- applies to many enterprises from those run on purely charitable sources to purely profit making businesses

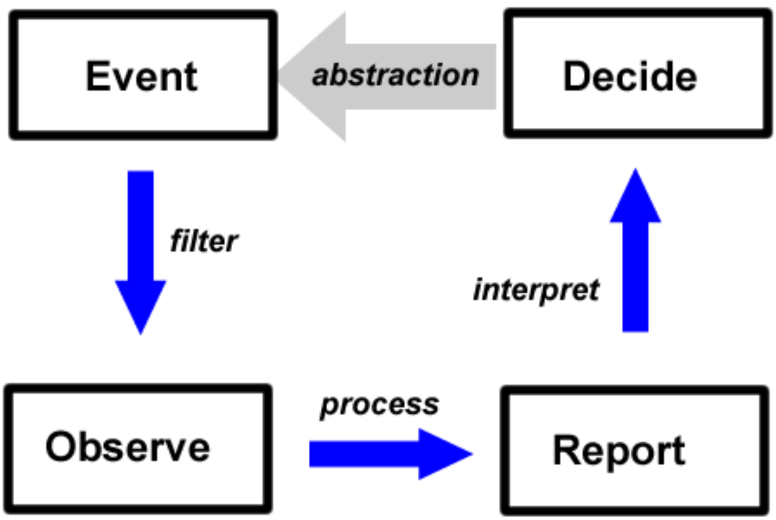
Focus on accounting in this text is useful because there are already many environmental and ecological economics texts and it is the first step in analyzing an issue, even for economists.

10.3 Principles of accounting

- purpose is to create a system to create information that can be used in the decision process diagram of accounting that creates an Abstraction of some real event

accounting consists of three steps that turn a real event into an "abstraction" that can be used for managers to make decisions

- a real event happens
- that is perceived and filtered by the accounting method to create an observation
- multiple observations are processed to create a report
- the report is interpreted by the decision makers
- accounting deals with what is observed, reported and frames how this information is interpreted



from Darrell Brown - "the hammer"

Note: This accounting method is very similar to how we have described the scientific method. The role of accounting is to decide what are the criteria for what gets filtered, which is very similar to the discussion over whether science only looks at objective data and leaves value decisions to managers, or in post-normal science where the values are brought right in at the beginning and considered. For accounting, the filter may be to only consider assets, liabilities and equities that can be represented by dollars.

A goal in accounting is "completeness", which is the accounting for everything that is relevant. One definition of relevant is to account for anything of value that could show up on a balance sheet. There are three types of value.

Term	Accounting definition/ Example	Environmental example
Asset	Potentially tradable	
Liability	Costs that are owed	
Equity	Total wealth – assets and liabilities	

10.4 Examples of different types of accounting

triple bottom line

this is a form of multiple perspectives: economic, social and natural capital

the framework for analysis of the triple bottom line includes:
triple bottom line - critique

ecological footprint

carbon cycling impact
water, energy, or other

ecosystem services

dollar value to replace biogeochemical cycles or physical attributes provided by ecosystems

rapid scan of ecosystems for health

such as stream survey techniques

estimating ecosystem services values

not all processes of interest can be measured

Johnson - Profit beyond measure (Johnson and Broms 2000)
Ehrenfield 2008
HBL

major flaw in economics

failure to account for scale properly - especially time and discount

behavioral economics making progress

Schumacher - Small is Beautiful (1975)

new - small is profitable

total community development through social entrepreneurship

return on investment
environment-poverty
improvement of human condition
role of economic development in poor and developing countries

primary consideration is financial feasibility
however - purpose is to promote social and ecological health

10.5 Two examples of environmental accounting

Tir Gofal system for agri-environmental preservation in Wales

assigning a value on pieces of habitat depending on its quality

goal was to preserve and care for agricultural, environmental and historical parts of the landscape

http://www.cpat.org.uk/services/tirgofal/tirgofal.htm
http://www.tynybrynfarms.com/tir-gofal.htm

Tualatin Water District/Clean Water Services
need to meet temperature requirements in the Tualatin River
could use equipment to cool water down before release (more expensive)

could arrange to have trees planted all along the Tualatin River upstream of their release (much less expensive - and has other ecological benefits, such as bank stabilization)
only one of these can be bonded (the capital equipment) because it is the only solution that has an "asset"
could change the definition of asset or change the law about what can be bonded (instead of paid for out of operating expenses)

REDD vs. Palm Oil Plantation to save biodiversity
Borneo
depending on the nature of the soil and forest - get different prices for saving the carbon
\$10 to \$33 per metric ton CO_2
\$2 to 16 per metric ton in the cost efficient areas
<!-- do they really mean ton of CO_2 or ton of carbon?-->
Carbon accounting in a forest
that might burn

10.6 Summary

Multiple Perspectives V4.2

Chapter 11: Values and World Views

11.1 Judgments and values are present in every problem

Scientific environmental management deals with problems. A problem is situation in which we have judged could be better or needs to be fixed. Thus even the idea of an environmental problem includes a judgment or decision relative to what is and what could be. Some scientists argue that science should be objective and not include values into their work because it might bias the results or sway the research in some subtle manner. This is definitely a cause for concern and there are times when science should be done as completely objectively as possible (such as in lab trials for a drug or pesticide or when developing a new method). But in environmental science and management the larger questions (i.e. larger than just one set of lab experiments or development of a new method) are problem driven, not curiosity driven.

Why an explicit treatment of values is important

It might seem like some approaches are more objective than others and thus less prone to errors introduced when the objective scientific results are passed for someone else to make a judgment. The idea is to quantify or routinize the decision process to such an extent that there will be little room for judgment error. The goal of objectivity often takes the form of a two-step, serial decision process in which isolated scientific data is passed to a separate level of managers to make the decision. This objective process doesn't eliminate judgment, instead it pushes all of the judgment to the beginning of the process. You start out by deciding to use a particular method of data gathering and analysis and then you agree (before you have any information sometimes) on an algorithm (set of steps) that will determine the outcome. We will see in this chapter that adaptive management principles can guide us to use a process in which the values are made apparent and are included from the very beginning and that this process can be rigorous, unbiased and extremely useful when addressing complex and wicked problems.

Different types of values

In this chapter we will use some terms in the following way (see below). This does not mean that other uses of these terms are wrong, but rather should alert you to the possible ambiguity or multiple uses of these terms elsewhere.

- values = relative preferences for material, processes and outcomes
  - felt values - strongly held values that are unlikely to change (Norton)
  - considered values - may be altered or negotiated
  - fundamental preference diversity- range of strongly held beliefs, similar to felt values (Page)
  - perspectives and tool diversity - range of ways people would perceive and address problems
- valuation = assessing many different aspects of any path or scenario for dealing with an environmental problem
- needs = biological requirements for living

Humans have requirements for living right now at a particular societal level. We will describe these as "needs" even though someone could choose to live with a lower level of resource availability or care. By this definition, discretionary or over-consumption would be the use of resources or demands on social services above what a person needs to survive and function within their society. For the purposes of this chapter it will be convenient to separate out decisions that are required to meet survival needs with those that can be addressed as a range of preferences. For example, it would not be a valuable use of time to have a long conversation in the community over how much someone who is dying of thirst "values" water. Similarly the very important discussion about what rights individuals in a society have to access to resources to meet their needs will not be addressed here. Instead we are focusing on how individuals within a society put values onto potential outcomes for problems.

11.2. Self-consistent sets of values make up worldviews

We often associate consistent sets of values as a particular worldview. For example, in regards to sustainability you can examine a population and find a range of values and combinations of values but there is a trend toward these sorting out into four major categories (Table 11.1). This sorting happens because some individual value statements are more likely to occur with some rather than other statements. For example, Cornucopian would value technology so highly they would also have a lower value on natural capital preservation because they think they can replace it with technology. However, this broad typology should not make you think that everybody fits into only one category or that there aren't other ways to have combinations of life values. For example, many people might self-identify with being a committed-environmentalist, but they really favor efficiency solutions to problems over strict conservation (like the industrial or accommodating ecologist category).

Table 11.1 Ecological/Sustainability World Views (Turner et al. 1993)

	technology	sustainability	other
Cornucopian	optimistic technologist	very weak	individual and property rights
Accommodating - industrial ecology	use efficient technologies	all capital is convertable,	equity for all

	and market incentives	weak sustainability	instrumental value in nature, utilitarianism
Communalist - committed environmentalist	preserve resources	strong sustainability	green economy collective interests take precedence over individual human interests
Deep ecology	preservationist severely limit resource take	very strong sustainability	broader definition of rights (animal, plant and earth system)

The purpose of this table is to be able to see the trends in general sets of values that stem from worldviews. Because these are linked to the history and identity of a person, many of these values would be strongly held and not negotiable.

Another description of worldviews can be derived for how groups think society governs itself and the role of individuals in that governance. This typology is also based on the hypothesis that there are only a limited number of ways that humans can perceive the world, and that certain dominant, self-reinforcing. There are four categories (van Asselt and Rotmans 1996):

Hierarchist:

- nature is robust within limits and can withstand stresses
- humans need well defined rules to function in society
- we should control nature
- value social stability
- many risks are acceptable

Egalitarian:

- nature is fragile like a complex ecosystem
- people are generally good and willing to cooperate if given the opportunity
- we need to prevent damage to nature
- value social equality
- most risks are unacceptable, we should follow the precautionary principle

Individualist:

- nature is robust and will be able to adapt to stresses
- people seek their own best-interest
- we should adapt to and exploit changes in natural resources
- value growth of society and economy
- comfortable with risks as necessary to promote growth

Fatalist:

- what ever happens, happens
- not very interested in being involved
- failures of others validate their viewpoint

The ecology/sustainability and governance typologies can be mapped onto one-another (Table 11.2). The match is not perfect, for example hierachists aren't always the same as industrial ecologists, but it's close enough to see how both typologies are useful and not contradictory. This comparison demonstrates that world views have favored metaphors to describe how the world works and preferred cognitive tools. Someone who maintains a narrow worldview would have his or her values reinforced by the type of information they collect (cognitive tools) and support their general mythology of how the world operates. Although you may agree with the premises that lead to a particular worldview, it is crucial that you learn about the other viewpoints and is able to assess your understanding based on a wide range of types of information. The multiple-perspectives framework is a start toward achieving this goal.

Table 11.2 Comparison of two typologies of worldviews, MEA scenarios, preferred cognitive tools and underlying metaphors or mythologies.

<table>
<tr><th>Governance world view</th><th>Ecology sustainability world view</th><th>MEA scenario</th><th>favored cognitive tools</th><th>example metaphor or myth</th></tr>
<tr><td>Individualist</td><td>Cornucopian</td><td>Techno-Garden</td><td></td><td>survival of the fittest</td></tr>
<tr><td rowspan="2">Hierachist</td><td>Industrial ecologist</td><td>Global Orchestration</td><td>quantitative systems tracking</td><td></td></tr>
<tr><td rowspan="2">Committed Environmentalist</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Egalitarian</td><td>Adapting Mosaic</td><td>cooperative nature of networks</td><td></td></tr>
<tr><td>Deep Ecologist</td><td></td><td></td><td></td></tr>
<tr><td>Fatalist</td><td></td><td>Fortress World</td><td></td><td></td></tr>
</table>

Another example of how these groupings of worldviews comes up in different context is the comparison between worldviews and human social development. Ken Wilber (2000) (check this reference - maybe it should be to Beck and Cowan 1995) elaborates on the stages in spiral of human development. In this model, humans develop socially beneficial attributes by moving through previous stages and developing the spirtuality and knowledge to interact with other people. The fourth, fifth and sixth levels are of interest to us. Wilber (2000) also describes the approximate proportion of the US population that are in this stage and the relative amount of power that they have in society. This is interesting because the level/world view that has the potential to impact the environment most drammatically, i.e. the individualist, has power out of proportion to their population. This is what we would expect if they are using natural resources, harnessing energy and driving the capitalistic economy.

Level 4 - Blue: mythic order (similar to hierachist)

- life has meaning, direction and purpose
- there are definite right and wrong
- there is a social hierarchy that is paternalistic
- about 40% of the population and 30% of the power

Level 5 - Orange: Scientific achievement (similar to individualist)

- states truth in individualistic terms
- rational machine metaphor
- nature can be understood and mastered
- about 30% of the population with 50% of the power

Level 6 - Green: Sensitive self (similar to egalitarian)

- communitarian values
- ecological network metaphors
- 10 % of the population and 15% of the power

Worldviews are essentially the way that people can use their values in a consistent manner to act on a information about the environment. Their perceived structure can be highly tinted by the cognitive tools they use to collect information and the metaphors that they use for comparison. In some situations, a worldview may or may not match the actual structure of environmental information. When it does match, this is called a "utopia". Your decisions have a high chance of being correct. When your view and the actual structure don't match, this is called a "dystopia". You would think people would change their point of view after seeing that their decisions were mostly wrong, but often they don't. As a trivial example consider what happens to someone who has a vision in their head that city streets are all laid out on an orthogonal grid and that most of the streets go through. When they are confronted by a set of dead-ends and one-way grids they become confused and get hopelessly lost looking for streets that go through. (Maybe the current generation of GPS users isn't as susceptible to this.) It takes some people a long time and many utterances to admit that they are lost. In the environmental realm world views maybe driven by an ideology that they are just not willing to give up. For example, died-in-the-wool deep ecologists may never agree that there are situations in which animals might be a good source of food, and may suffer malnutrition and personal deprivations because of this. We won't focus on individuals here, but instead on the general idea that society could be made up of a range of these worldviews and that one view might be dominant for decision making.

11.3 An overview method for including values

This chapter presents one possible method for bringing values into the conversation of how to address environmental problems. It is very similar to the framework for using multiple perspectives and draws heavily on the three tenets of scientific adaptive management of experiential, scale sensitive, and place specific (Norton 2005). The parts of this method will be listed below and then explained in more detail.

a. Pluralistic conditions must be established to support the aggressive inclusion of many different points-of-view and value sets. In essence this requires that there will be multiple criteria that are on different scales and don't converge to one underlying value.

b. There must be a definition of what place and people are responsible for the resource and the solution. This community must declare their commitment to solving the problem. All the people and sub-groups within this community have to respect pluralistic approach and a democratic process.

c. Disputes will be resolved based solely on the evidence that is available for this decision at this place at this time. Pre-experiential, i.e. ideological, solutions will carry much less weight. The shared commitment to the problem and the shared experiences will help the community create a language for describing the problem and its evaluation.

d. The process will require creating a diversity of scenarios or paths and then evaluating these paths with evidence and indices of progress. Competing interests may favor both different paths and the employment of different indices, but all indices must be applied to all paths.

Pluralism

First of all, pluralism is the commitment to seek out and nurture conditions that will allow the presentation of different opinions, values, and methodologies. These conditions will support respectable and involved participants in their efforts to get their thoughts, questions, and values heard. Not everyone deserves to be heard in these debates. There are often people who aren't committed to pluralism but use that as a platform to voice their unfounded anti-egalitarian complaints. If they don't respect the others in the community then they have no right to speak or present their ideas in this format. That may seem harsh and anti-democratic but it's actually the reverse. Only people committed to the ultimate democratic resolution can be involved. Everyone involved needs to be able to say "I respect your right to make that claim, but I disagree and here is why." A common expression of the lack of trust and respect in these decision making processes is overt or disguised scoffing at an idea. For example, an administrator might dismiss out-of-hand a suggestion because he or she thinks it is infeasible. That judgment of infeasibility needs to be examined respectfully, not just throwing out the idea.

Open fora for discussion and dissemination of different scenarios are often not pluralistic in practice. It seems that many agencies might organize stakeholder meetings that serve the main purpose of allowing the public to vent over an issue. If they hold enough community meetings, people get worn out objecting and the process moves ahead. This is not pluralism because there was really no mechanism or time built into the process to consider these ideas as anything but complaints. Truly bringing values in the process will take more time than just allowing people to vent. Another common form of pseudo-pluralism is to play the Goldilocks game. Planners or managers present a wide range of scenarios but with the fix is already in for the plans that are not too hot or too cold. You should be able to detect this through both the discussion and through how the scenarios have been framed (see below under skills and assets).

Community and Commitment

Environmental problems are place specific. They may share some attributes with other problems and this might allow some degree of generalization, but one of the three tenets of adaptive management (Norton 2005) is that problems are place specific and that you have to understand the immediate context as well as the larger scale framework. There are many issues of dealing with scale in environmental problems (ref - Rueter in prep) and one of them is to decide what size of community can participate in the conversation on this particular problem. The community maybe the list of all the people and group that are involved in this specific problem and who can demonstrate that they are dependent on the results being accepted by that same community.

Once a community has been identified, the next task is to get that community to unanimously agree to a statement of goals for this specific process. The statement of these goals may need to be inclusive and maybe vague or ambiguous on particular topics. The important point is that everyone who is in the community has to agree to work toward those common goals. This is the crux of the problem because the rest of the process depends on defining a community that is willing to work together.

Experience as the primary arbiter of disputes

In the adaptive management process described by Norton (2005), one of the three tenets was that all the decisions need to be made based on experience or experimental evidence from that particular instance of the problem and that pre-experiential or ideological approaches not be allowed to serve as evidence. Another point that he makes is that values are also up for discussion and revision in this process and that every management experiment is also an experiment in values.

This requirement leads to a major problem that will be discussed below, which is that we need common experiences to build the language needed to incorporate values into the solution. Thus experience serves as both the main source of information and the platform on which to construct language about values. This means more experiences that are directly related to the problem are highly desirable but direct experience is a time-intensive way to learn about the problem.

Evaluating paths with data and indices

Once the community has been identified, committed to solving the problem and made their preferences and values known the final part of the process is to get groups or individuals with different visions on how this problem might be solved to create scenarios for their suggested solutions. These scenarios need to address:

- a description of the situation and process
- the scientific information at hand and what's needed
- what they suggest should be done
- how they will collect direct information
- what combinations of factors they propose (indicators) will accurately reflect progress toward their preferred outcome

These scenarios need to be very concrete descriptions that can be described, presented, discussed and modified. The key part of this part of the process is that the discussion needs to focus on these scenarios, the technology, knowledge and assumptions. The discussion must be limited to what the community agreed and committed to solving. It is very easy to widen the problem by adding in other issues. If that happens, the community must agree to the larger scope and the composition of the community must be examined to see if it needs to be more inclusive as well. A common example is to worry about whether the particular place-specific solution represents a variance or exception to policy and thus should be avoided because of that danger. To bring in this issue is to generalize from the solution proposed to a wider scale. It has to be explicitly in the scope of the problem statement from this community to address policy questions posed by their actions before it is legitimate to consider policy implications.

Skills and assets required to negotiate the use of values

Just as a scientific experiment or management action would require knowledge and skills, the inclusion of values into a deliberative process would require people with skills in managing groups and information flow. Most of these are general skills that you learn by studying how group processes work and by working with groups of people. There are a few skills that can be very useful:

- framing and reframing the question so that it has neutral standing
    - avoiding or demeaning pejorative words

    - requiring assumptions be made explicit rather than to hide in the jargon of a particular discipline or profession
- maintaining mutual respect
    - eliminating people who are not committed
    - eliminating people who have espoused values that don't match their real values
    - rejecting scoffers
- identifying who is in the community
    - knowing when to revisit the community composition and commitment statement
- dealing with preference and instrumental diversity issues
    - knowing how to concoct subgroups that will function by drawing on all the skills needed
    - knowing when and how to have a broad ranging discussion on the underlying values
    - knowing how to maintain everyone's felt or central values and yet to focus on the area that requires compromise
- building trust in the community
    - drawing on a host of mechanisms and activities that allow people to trust each other

For our purposes it is important to realize that working on group problems develops these skills where there is a variety of opinions and personalities in play. In addition, <!-- making a claim --> the negotiation of situations involving environmental problems and values requires practice in this domain. Other experiences from business or education, may be helpful but the nature of the complexity with environment/humans/values problems are different and can be facilitated with particular approaches. For example, in business there is an underlying assumption of fiscal viability and a hierarchy within the company that makes certain solutions much more efficient and effective than other solution paths. Similarly, if the environmental problem is in a working community in which one member is a government employee and has a very strong commitment or responsibility for the solution, the solutions will probably follow governmental policy closely. An example could be the restoration of a stream that is in a state park. The park officials would probably play a controlling role in both problem statement and identifying solutions. However, many problems are in less-defined communities and the problem has been defined with multiple non-convergent criteria that extend over different time and space scales. In this case the solution will probably look a lot more like a social entrepreneurism approach than a business plan or an agency document.

11.5 The importance of experience and the language gap

A major barrier to incorporating values into environmental decision-making, according to Norton (2005), is the gap in usable language at the nexus of science, application and values. I think a major reason for this is that it is very inefficient to learn facts about the environment through experience, and yet that experience is just what we need to define our values. Efficiency in learning facts should not be the goal of environmental or science education but it has become prominent under the paradigm where facts are objective and the science should be objective. Instead we need much more effective learning about the environment which would be infused with the value that is inherent and inseparable for studying authentic problems. Obviously most educational activities will have to be using contrived or practice situations. (We don't want First Graders learning about forest fires by starting them.) But, the connection to the environment can be genuine even if it is a practice exercise.

I think there are four parts that contribute to this language/experience gap for students:

1. We need to extend our language to describe key elements of value and environmental impact and our feelings about those issues.
2. We build our language by sharing experiences as we work toward common goals.

3. Because of our schools and living communities, many current students have been isolated from direct experiences with resource management and other environmental issues.
4. To correct this, we have to intentionally construct many practice problem solving experiences for students in the environment.

11.4 Importance of trust

Since what people claim to be their preferences and values can not be independently verified, it is necessary to build trust between the participants. There are a few situations where economists or other social scientists might be able to develop tests for contingent value or order of preference, but these are usually single dimension problems with coherent values (not the non-convergent multiple criteria problems that we are most interested in here). There are several conditions that help establish trust. First, it is crucial to have an open dialog that allows for questions and responses. Publishing statements or position white papers is not sufficient for this purpose, even if they are very well crafted. Second, some aspects of the statement and personal attributes need to be verifiable. This includes the job title, address, employer or source of funding, close associates, and previous projects. These details are both easy to publish and to fact-check on the internet. Third, any dominant stakeholder or leader needs to have a consistent stance all the way from the specific issue at hand, to their personal philosophy, and actions. Inconsistent stances or personalities are red flags for trust issues. Fourth, the person should be identified with a network of people who can vouch for their reputation or provide background details. If all of these criteria sounds like a job interview, that's close, because working with someone on a significant environmental issue could be a long process that takes as much time as a regular job.

Although it seems very personal or even petty, research has shown (Fukuyama) that the availability of channels for rumors is also an important factor for building trust. If there are channels that would transmit a rumor, but you haven't heard one about the organization or person of interest, the lack of negative information can be significant. This type of trust-building highlights the general importance of back-channels for information that are separate from the direct information flow that is being used to support the decision or project. This can be through social networks, religious groups, community act ivies, kids going to school together and many other mundane activities that are not usually considered important in scientific adaptive management.

11.5 Examples

Example 1: World views and different attitudes toward global population growth

This example is from van Asselt and Rotmans (1996)

"The demographic data do not allow us to derive an unambiguous understanding of the factors that trigger structural changes in fertility behaviour, i.e. the so-called "fertility transition".

"plausible and consistent **hierarchist** interpretation of the scientific uncertainties, namely: the myth of nature, the perception of human nature and the driving force."

nature is robust within limits	vigorous population growth will end up in disaster as carrying capacity is exceeded
physical limits to population	
humans follow governing institutions, such as state and church	fertility decisions reflect state or church statements
management style is to control	family planning view, high birth rates are result of lack of availability to contraception

egalitarian

life is fragile	
ecocentrism - humans just part of nature	population growth violates quality of life for all
tolerable population limit	determined by social and ecological criteria
generally preventative	
fertility choices	modernization - "conditioned by social, educational, culture and economic conditions they face, "
policies	improve conditions of women and children

individualistic

nature is an abundant resource that it takes skill to use fully	
people are resources - intellectual capital	
changes in fertility	induced by socio-economic situations of individuals
markets	will provide contraception and other services if needed
population policies	*laissez-faire* to allow market mechanisms

Use dynamic uncertainty on these estimates in 2100 the population in:

hierchist 2.5% of simulations had
about 20 billion
egalitarian 2.5% of the simulations
had about 10 billion
individualist --------------------------
20 billion

Pg 146 - The combination of these utopias with "classical uncertainty analysis" results in "images of the future that are probable in the light of state-of-the-art knowledge perceived from a variety of perspectives."

Risk assessment by comparing predictions from a perspective with different actual outcomes - i.e. dystopias

<!-- risk is associated with how well the management styles do when paired with the wrong worldview -->

hierachistic strategy (which focuses on family planning)

with individualistic world view --> 15 billion
people
with egal worldview --> similar to hierachistic
utopian match

but not stable - continuous growth

family planning applied to indiv or egal world has
less effect

stabilization of world pop below carrying capacity
is "rather risky"

egal strategy (which focuses on education and legislation)

with indiv worldview --> high fertility : risky
strategy
with hierarch worldview --> dystopian situation is
overshoot and collapse

individualistic management (population is not considered a problem)

> instead of continuous growth - results in stabilization around 11 bil
> this management is "not considered to be risky"

<!-- worst mismatch seems to be egalitarian strategy in a hierarchical world because it results in overshoot and collapse-->

pg 150 - Robust strategies

> "egalitarian governance in a hierachistic world and hiearchistic governance in an egalitarian world are problematic"
>
> mixed policy - combination of education and family planning are compromised and can lead to outcomes that are acceptable by both

Example 2: World views and different attitudes toward atmospheric CO2

The issue is stated by van Asselt and Rotmans (1996) as:

"The fundamental controversy pertaining to the climate debate can therefore be summarized as: Is the global climate being significantly and irreversibly disturbed, and if so to what extent, at what rate of change and with what regional pattern, and what are the human and environmental consequences?" (authors' italics)

"whether we should act now or wait until more is known about global climate change and its consequences for man and environment."
Compare the management styles and worldviews to look for mismatches.

- where a world view description (think of this a hypothetical reality)

- is matched up against policy and management approaches that are based on a different worldview
- i.e. what if the world doesn't work the way you are trying to manage it?
- look for the best and worst cases:

Table summarizing different worldviews and how they think the climate will react based on a version of nature

	CO2 impact on temperature	*because nature is*
Hierarchist	amplifying	tolerant if kept under control
Egalitarian	strong amplification	fragile
Individualist	high dampening	resilient, robust

CO2 and temperature relationships are predicted to be:

note that individualist predicts lowest temp increase for medium CO2

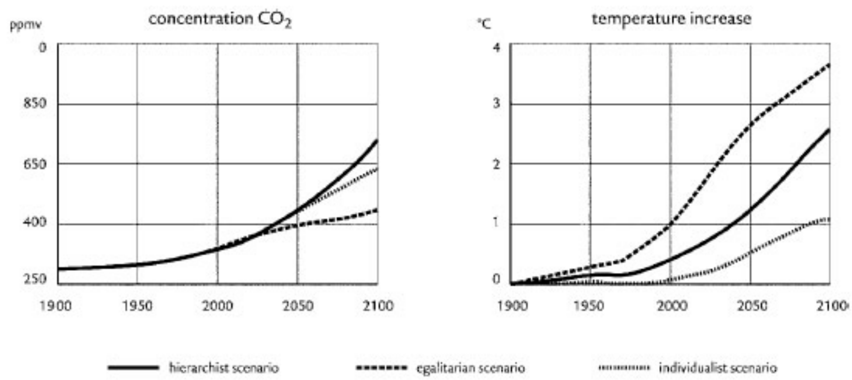


Figure 7. Outputs of utopian experiments in terms of CO_2-concentration and temperature increase.

Figure from van Asselt and Rotmans 2002

As with example 1 - the worst mismatch, i.e. the riskiest position in this case is to take the individualist strategy (that everything will damp out) in a egalitarian or even hierarchical world (where there are strong destructive amplifying effects).

11.6 Summary

to be added later

Chapter 12: Working framework for multiple perspectives

12.1 Outline of the method

There are four components of the working framework:

1. observation and direct experience
2. creation of narratives using viewers and information from experts
3. analysis of the overlap and differences between the narratives
4. application of these ideas to the problem statement and using adaptive management

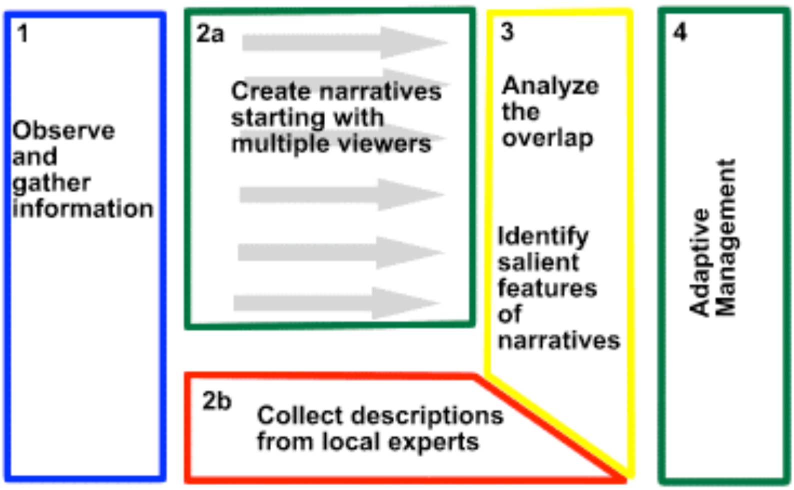


Figure 12.1 A schematic of the "multiple perspectives framework"

Observe and gather information

Primary data and some direct observations need to be gathered from the location to complement the information that can be obtained from literature maps and other references sources. The group responsible for employing this multiple perspectives framework must have first-hand and personal experience in the specific location and exposure to the problem that is being addressed. This requirement is essential to the "method of experience" described by Norton (2005). The data, observations and information should encompass the physical location and processes, biological and ecological features, society, values and economy. Familiarity with the starting set of "viewers" will help the observer understand what information will be needed.

Create narratives

Independent narratives of the situation will be created (from the information gathered) using as many of the "viewers" as possible. For any environmental situation, it should be straightforward to employ the "systems", "network", "scale", "games", "risk/uncertainty", and "accounting" perspectives. It may also be possible to employ a "values/world views" approaches if you have access to discussions with local people. The structure of these viewers force you take a constrained approach to the situation, but by doing so allow you to avoid missing information crucial to that view. Each viewer-specific narrative will provide an internally consistent or coherent description of the problem. The narrative from each viewer will always contain certain salient features (which are important in the next step). Any one view will not capture the richness or even full scope of the problem.

There are also many other approaches that could be useful but not mentioned in this book. A few examples are:

- interviews that look for community values and preferences
- maps, geographical information systems, and other spatial approaches

- historical drawings (such as used by Wood (2000, 2003) to study land right movement in El Salvador)
- community network analysis (such as performed by Granovetter (1982))

Local experts can also provide their own narratives. Individuals and representatives of groups already living and working in this location have constructed their explanation of the problems and described their approach to dealing with these. After collecting the information, there will be some loss of richness when they are translated using terms to those that can be compared to the viewers. It might be useful to save the original narrative separate from the translated version however this is not always possible (for example if you have to construct the original narrative from conversations, that translation has already been built into your version).

There should be no attempt to force any of these narratives to converge. If one person is creating all the narratives, it is important to be able to clear your thinking and approach each view with a fresh slate. If a team is used to study the problem, it may be useful to create the narratives in isolation from each other and even have different members of the team create duplicate narratives at the start. Team members who are more experienced with a particular view should be assigned that view. Writing a narrative from one view is a skill that should improve with practice.

In the process of addressing these problems from multiple perspectives there is a valuable opportunity to examine or suggest a wide range of problem analysis techniques or heuristics. These heuristic approaches are not explicitly part of the viewers, but thinking about problems using this framework should trigger some innovation. This opportunity is described by Page (2007) as one of the big benefits to be gained from diverse working groups and one of the values of a deep education for individuals. According to Page (2007) difficult problems that have multiple dimensions are much more likely to solved by employing a toolbox of heuristics that stem from the multiple disciplines and backgrounds of a diverse team.

Analyze and compare the narratives

The narratives from the viewers will identify salient features of the problem, such as the mass balance of water or the connectivity of the ecosystem to the local community. See Table 1 for a review of some of these salient features of each viewer. A summary of the characteristics from each view will be compiled and these characteristics compared. Some parts of these descriptions will be expected to overlap because they really are different ways of looking at the same phenomena (such as the flow of nutrients from the systems view and some aspects of connectivity from the network view). Other outcomes of viewers should not be expected to overlap and should not be forced to be convergent. Non-convergent components of multiple narratives are a crucial part of the multiple perspectives framework. Without the ambiguities the whole framework will collapse to be a single disciplinary view and defeat the whole effort. (This approach is very different than in in sister disciplines, such as biology or chemistry, in which the multiple representations are expected to converge and reinforce each other.)

Table 12.1: Summary review of several salient features of each viewer. If you see these features in a problem, it may be useful to try using the viewer to elaborate other relationships of characteristics of the system.

Viewer (Chapter)	**List of salient features**
Patterns (4)	• spatial or temporal patterns • direct observations • looking for likelihood of a

	hypothesis to match the observations
Systems (5)	• reservoirs or stocks • flows • control of flows by some process • closed or open system • positive or negative feedback
Scale (6)	• range of physical sizes, temporal durations or rates • key processes of different magnitudes
Network (7)	• nodes and connections • connectivity • spatial grid with connections • resilience
Risk (8)	• risk, exposure • bounded rationality • uncertainty • indeterminacy
Games (9)	• multiple participants • limited cooperation • payoff matrix • precautionary principle
Environmental Accounting (10)	• asset • liability • "completeness"

Values and World views (11)	*to be added later*

Terms	**Explanation**
Systems -flow vs. Network - link	In the systems view a flow between stocks or source/sing and a stock can only be the units of whatever is in that stock per unit time. In the network view a link can be any relationship between the nodes, material, energetic or informational.
Scale - total extent vs. Systems - boundary	In the Scale view the total extent of the system is a value that represents the largest physical dimension. In the Systems view, the system boundary has to be more exactly drawn and this boundary represents what is being counted or measured (represented by stocks) and what is coming and going outside of the system being studied (using sources and sinks). The Systems view demands a much clearer definition of what's in and what's out.
add more later	

add more later	

The focus of this approach is to identify conflicts or ambiguity, but we know that convergent or redundant information is useful. For example, if you create an accounting view of a particular project and it reinforces some of the institutional and ecological benefits, then this would be similar to the "Triple Bottom Line" approached used in some businesses. The Triple Bottom Line is a good goal for sustainable management, but that approach has problems if the financial accounting doesn't line up with the social and ecological accounting. It provides no method for getting from that discordance to meeting the goal.

12.2 Adaptive management

The three major tenets of scientific adaptive management (Norton 2005)

- *experimental and experiential* (all information must come from direct experience)
- *multiscalar* (study and management must consider a wide range of scales)
- *place specific* (all problems have components that are unique to their location and some are dominated by this characteristic)

The first three steps of the MPF feed into this management, in particular the focus on disambiguation or resolving conflicts rather than focusing on what is established by convergence. Pahl-Wostl (1998) claims that the purpose of an advanced perspective on management is to move beyond just reducing uncertainties and identify indeterminate aspects of the problem. This is an often misunderstood aspect of what is called "consensus science", which is really a process for a group of scientists to compare what they probably agree on, not for political reasons, but so that they (as a collaborative community with social goals) can more quickly move to the uncertain aspects of the problem. While the media is focusing on the 90% or more agreement of global circulation models, the scientists are organizing and moving aggressively to explore the 10% of disagreement.

Scientific adaptive management is a powerful approach. It is philosophically grounded in a pragmatic approach to problems and builds on a different kind of science than our sister disciplines in the natural sciences, i.e. it is fundamentally mission driven rather than curiosity driven. This results in us (environmental science) setting the bar for what we accept as enough information to take action on as different for what we would consider scientific proof or legal proof. Just by making these distinctions we have differentiated ourselves as an applied, mission driven discipline but also clarified that we are not driven by ideologies (as often claimed) but grounded in scientific evidence and direct experience.

12.3 Conclusions

Problems that are of crucial interest in our discipline are complex, difficult, and wicked. There are no simple, one-size-fits all solutions to these problems. For the environmental scientist/practitioner it is not a task of sorting through a list of current best practices for the correct solution. That may be a good first cut at the literature. The problems will have place and history specific attributes that require additional direct experience. These problems are not only place specific but the nature will change with time, again a characteristic that is addressed by scientific adaptive management and requiring different information and involvement.

Applying the multiple perspective framework requires a person or team to commit time and attention to a problem. Several examples are presented elsewhere in this text that illustrate the timeline of projects. Working on the multi-faceted aspects of a problem by devoting the time individual or with collaborators can be very rewarding. In order to meet the requirements of MPF, you would personally experience the location, the processes and interact with the people who live and work there. It may not be as efficient as downloading data off Google but, in the end, it's both more effective and satisfying. When you read some of the examples and case studies, you should think about what it would be like to be talking to experts, collecting data using many types of observation and instruments, as well as combining information from a wide range of resources. You might also want to imagine yourself working along side many different people, being exposed to all types of weather, and traveling to sites near and far. You should consider the multiple perspective framework as both an integrated set of academic and intellectual tools but also a key part of a challenging profession.

PART 4: ENVIRONMENTAL ACTION

After we install the solar panel,
maybe we should fix the ladder.

Multiple Perspectives V4.2

Chapter 13: Innovation is required to solve complex environmental problems

Innovation is required to solve complex environmental problems

- The world is complex and maybe even getting more complex
  - Define complexity
    - See Homer-Dixon page 104 for six features of complex system
    - Multiple things
    - Dense web of causal connections
    - Interdependence
    - Some degree of synergy
    - Openness to environment
    - Exhibit nonlinear behavior - thresholds
  - Human control over the environment has increased the pace of change
  - Natural systems that underlie these are sensitive to flipping across thresholds
- Addressing these new problems will take new approaches
  - Ingenuity, technical and social
  - Homer-Dixon asks
    - Is more ingenuity required to meet these increasing problems
    - Can societies provide enough ingenuity
- Some of these are old problems that are taking on new dimensions
  - 40% of people use firewood, charcoal, etc for cooking about ½ of these that is the primary source of energy

    - more than 1.2 billion people lack access to clean drinking water
    - Smil – 40% of all protein consumed by humans requires synthetic fertilizer
    - Give example of innovative responses to this – such as treadle pump
- Other problems are from combining component systems in new ways or on very different scales
    - Examples?
    -
- Understanding of problems is based on models
    - Using a new model, that is not generally in use or accepted, will provide different insight
    - Can add value, maybe by connecting to other values
- Ingenuity gap
    - Problems we create vs. our ability to solve them
    - Unintended consequences of our actions (Tenner)
- Innovation requires
    - Different approaches
    - Institutions that can employ these approaches
- Complexity paradigm
    - Return to these problem statements
    - Complexity may lead to collapse (Adams, Tainter)
- Example:
    - Renewable energy sources are complex
    - Underlying ecology plus forcing from humans for harvest/exploitation
    - Can cause collapse from naturally occurring variation
- Conclusions
    - Environmental resource scarcity may require innovation
    - Society needs to support conditions that foster innovation
        - If they don't then innovation may not keep up

    - Bigger problems, insufficient economic growth
    - Schumpeter – innovation becomes part of the economy
  - Around the world, different issues but facing the same question about whether can rely on human ingenuity to solve the questions fast enough

Chapter 14: Scientific Adaptive Management

NOTES ONLY

- Synopsis of Norton
- Scientific adaptive management is experimental management, like practiced by Aldo Leopold.
- Norton claims – facts and values have to be discussed together
- Manage ecosystems for “health”
    - See Costanza, Norton & Haskell 1992)
- The method of experience
- Pg 72 – key variability is how quickly a culture can learn and adapt to changing environment
- Different types of science
    - Mission based
    - Curiosity based
- 3 tenets of SAM (pg 92)
    - experimentalism
    - multi-scalar approach
    - place sensitivity
- adapt management is based on value-laden, mission driven science (rather than pure or curiosity based science)
- wicked problems
- values and commitments
- integrated analysis and action
    - scenarios
    - risk and uncertainty
    - consultancy
- communities that solve environmental problems develop good governance (claim with examples)

Chapter 15: Engagement and Environmental Entrepreneurial Solutions

The lesson of keystone species

A "keystone" species is one that has a very strong impact, and continuing control over, the structure of its ecosystem. This species doesn't necessarily control the most energy flow. In fact in most definitions a keystone species has to have a much more dramatic effect on its ecosystem than simply predicted by its energy or abundance. I'll use several good examples to illustrate the types of structures that are affected.

> Alligators create wallows that are the source of freshwater in the Everglades. It is not the alligator's ferocious demeanor or that it is a top predator or the total energy flux through alligators (which is relatively small), but their creation of water holes that help other critical species make it through dry times.
>
> Elephants knock down trees to create openings in the forest and keep the savanna as savanna. They don't do this by eating the trees, but by simply knocking them down to get places.
>
> ?Bats - maintain dispersal and diversity in mangrove?

In all of these examples there is a critical texture or quality of the environment that comes under the control of the keystone species. That characteristic serves multiple functions that should be much more evident from multiple perspectives.

NOTES ONLY

- SAM maybe employed at large scale
    - Governmental projects
- Some problems can be addressed at small scales more effectively.
    - Schumpeter
    - Small is beautiful – Schumacher
    - Small is profitable (
- Requires coordination of groups or engagement of individuals
    - How does this happen at small scales
    - Individuals get involved
        - Might be required to
- Method – control from the middle of behind
    - complex systems are not easily ruled
    - kings give up direct rule to democracy (but not necessarily economic clout)
    - complex systems have multiple layers and key points to connect them
    - wicked problems
    - control from the inside
    - Ashby's Law of requisite complexity
    - ILP - spatial - temporal
    - cellular automata, add or subtract a square when the system is near the critical point
    - 4 rules for controlling a complex system
    - Adams power diagram
    - other predictions about social power vs. technological power (see Fukuyama)
    - Meadows 10 things you need to know
- Examples – revisit
- control of the demographic transition with little levers
    - conditions that lead to demographic transition that aren't the macro-economic national transitions from pre-industrial through post-industrial
    - like microloans

  - one challenge may be how you can assess or account for these
- the answer is to manage for health of the system - sustainable health
  - recognize patterns from HBL
  - some systems are at the edge of chaos, with a tipping point,
  - create chaos move toward the tipping point
  - make systems more complex by adding texture to the linkages
  - add values where there weren't any
  - this is different than crisis management - that is reactive
  - you have to take time to set it up and understand the system
  - examples:
  - daphnia control of AFA
  - marsh spreading - ILP
  - Elizabeth Jean Woods - El Salvador

Multiple Perspectives **V4.2**

Chapter 16 End note: The tenuous path to sustainability

16.1 Sustainability may be an emergent property

What if we were to view sustainable societies and economies as emergent systems; how would this change our understanding of our goals and the transitional path or paths? This paper develops a short list of the characteristics of emergent systems that share elements with lists of goals for sustainability. The emergent system model of sustainability also suggests that the transition to sustainability should be viewed as potentially having multiple paths. In the emergent view of sustainability there are no goals, instead policies and regulations would have to be used to create the conditions that promote undirected change. Given the dominance of the planning view and the power of emergent systems view, the paths toward sustainability will probably combine regulatory structures that may require support from emergent processes.

The prevailing ideas for moving to sustainability are built on the underlying belief that our social and economic systems can be directed to move toward well articulated goals through appropriate management strategies. In this view, governments and other management groups develop goals, objectives and specific actions that need to be taken to accomplish this directed change. This paper explores an alternative view of the sustainable outcome, i.e. that a sustainable society and economy is the result of emergent behavior of the citizens acting on a very simple set of rules. This view is not meant to replace the importance of some level of central planning and governmental involvement, but to provide us with additional ways of thinking about the very complex problem of moving a society toward a sustainable future.

The many definitions and examples of "sustainable" societies and economies share elements with emergent systems. One way to appreciate the diversity of views on sustainability is to survey the introductory environmental science textbooks. Each text has its own list, and these lists differ on many levels. Nebel and Wright (2000) compiled a list of principles for how natural ecosystems work and suggested that these natural processes illustrate how a human economic/social/ecological system might work. Raven and Berg (2001) provide a list that is a mixture of goals, processes and rules that relate to sustainability. Chiras (2001) compiled three lists; one list of beliefs that represent sustainable ethics, a second list of actions that individuals can take that would support moving toward more sustainable society, and a third list that gives ecological, social and economic principles for sustainability. Chiras also argues that people need to expand their space-time scales to move toward sustainability; more people need to be aware, value and act on space scales that expand from self to family, community, state, nation and world and on time scales that extend from the present toward multiple years, centuries, and in fact eternity. The text by Miller (1985) may represent an emergent view, he claims that his text is based on "nine deceptively simple theses" that include principles and processes. His final thesis that "It's not up to "them," it's up to "us." " is a good description of emergent systems. Introductory textbooks are important in that they describe the domain for disciplines and they set out the basic metaphors and heuristic approaches expected to be used in these disciplines. Popular metaphors such as indicators as the "dashboard" (Chambers et al. 2000) or a "blueprint" for sustainable society (Pearce and 2000) are obviously based on a control and planning view of sustainability. Our students need to be equipped with additional metaphors for problem visualization based on emergent systems and complex behaviors.

For this paper we will examine national goals established by the Clinton administration (Table 1). The items in this list are uniformly stated as mid to long-term goals for the United States. These goals represent desired behaviors of a system that is presumed to be sustainable. Emergent systems have identifiable behaviors that set them apart from centrally controlled or hierarchical systems (Table 2). The goals for sustainability, as stated in Table 1, contain elements and ideas that are consistent with emergent behavior. (This is a necessary but not sufficient condition to argue that sustainability is an emergent behavior.) We can read sustainable characteristics into the goals as stated, i.e. we can map Table 2 onto Table 1. Some of the goals depend on individuals or emphasize individual action (Goals 1,2,3,6,7 and 10). Some of the goals describe the results of individual actions (Goals 5, 6 and 7) based on the individuals ethics, attempt for a quality of life or civic engagement. Another set of goals implies changes at a different scale (Goals 4, 5, 6, 8, 9 and 10) with phrases such as "ensure long term", improve the health", "move toward" or "international". Again, the purpose of this examination is to gain insight to the characteristics of a sustainable society in such a way that we will be able to move toward that condition. If "sustainability" were one possible emergent property of our current social structure, then we would act differently than if it were a consequence of top-down policies and incentives.

Table 1: National Goals Toward Sustainable Development Source: President's Council on Sustainable Development (1996).
Goal 1: Health and the Environment. Ensure that every person enjoys the benefits of clean air, clean water, and a healthy environment.
Goal 2: Economic Prosperity. Sustain a healthy U.S. economy that grows sufficiently to create meaningful jobs, reduce poverty, and provides the opportunity for a high quality of life for all in an increasingly competitive world.
Goal 3: Equity. Ensure that all Americans are afforded

justice and have the opportunity to achieve economic, environmental, and social well being.
Goal 4: Conservation of Nature. Use, conserve, protect, and restore natural resources- land, air, water and biodiversity - in ways that help ensure long-term social, economic, and environmental benefits for future generations and ourselves.
Goal 5: Stewardship. Create a widely held ethic of stewardship that strongly encourages individuals, institutions, and corporations to take full responsibility for the economic, environmental, and social consequences of their actions.
Goal 6: Sustainable Communities. Encourage people to work together to create healthy communities where natural and historic resources are preserved, jobs are available, sprawl is contained, neighborhoods are secure, education is lifelong, transportation and health care are accessible, and all citizens have opportunities to improve the quality of their lives.
Goal 7: Civic Engagement. Create full opportunity for citizens, businesses, and communities to participate in and influence the natural resource, environmental, and economic decisions that affect them.
Goal 8: Population. Move toward stabilization of U.S. population.
Goal 9: International Responsibility. Take a leadership role in the development and implementation of global sustainable development policies, standards of conduct, and trade and foreign policies that further achievement of sustainability.
Goal 10: Education. Ensure that all Americans have equal access to education and lifelong learning

opportunities that will prepare them for meaningful work, a high quality of life, and an understanding of the concepts involved in sustainable development.

Table 2: characteristic properties of emergent systems The quotes from Johnson (2001) illustrate the major differences	
based on individual actions	"they solve problems by drawing on masses of relatively stupid elements, rather than a single, intelligent "executive branch" "
individuals follow simple rules	"The movement from low-level rules to higher-level sophistication is what we call emergence." "They are bottom-up systems, not top-down."
behavior at larger or longer scales	"agents residing on one scale start producing behavior that lies one scale above them"

16.2 Social and economic transitions

Our understanding of any socio-economic transition is likely to refer to the classical "demographic transition" model. In the demographic transition model, populations first go through a decrease in mortality due to health care and improvement in sanitation. This is followed by a decrease in the birth rate that is driven by individual families determining that there are economic benefits to having fewer children. This transition is seen as having one dominant sequence of path that is related to the industrialization of the society. Unlike the classical demographic transition, the transition to a sustainable eco-socio-economic system will undoubtedly be multidimensional and would have multiple potential paths. It may not only be that there are many feasible paths, but it may be desirable to have many paths simultaneously. The overall transition would contain at least the following contributory changes:

- zero population growth (Cunningham and Saigo 2001)
- high efficiency energy use and production (Cunningham and Saigo 2001)
- sustainable economic development that maintains competitiveness, potential economic growth greater than debt (Chambers et al. 2000)
- ecological footprint less than region's natural resources (Chambers et al. 2000)
- social change to postmaterialist values (Inglehart 1995)
- coordination, cooperation and interdependence between regions (urban/rural, developed/undeveloped, north hemisphere/south hemisphere) (Cunningham and Saigo 2001)

The transition to sustainability is a specific example of the general case of problems that are generally perceived to require multiple, simultaneous changes to be successful. For example a negotiation between three vendors and suppliers in which A supplies B, B supplies C and C supplies A, would require an agreement between all three before the transaction could be completed. The emergent view of this problem would be that there are multiple agents of each type that are free to make pair wise negotiations. As these negotiations proceed, the system reaches the general behavior of circular flow without any requirement for simultaneous agreement. In addition, variations in our society could lead to multiple paths.

For example one region could decrease population growth rate that would lead to a decrease in their ecological footprint, and then a realization of postmaterialist values, whereas in another region, the overall transition might be driven by an initial reduction in consumerism. The emergent view takes advantage of these multiple paths rather than assuming there is a single optimal path.

For the purposes of this paper the two main questions are: what type of rules would lead to a sustainable transition and what type of conditions has to be in place for people to be receptive to these rules? The rules have to be stated at the level of individual citizens and choices that they make. It would be impossible to define a specific set of rules; instead I am suggesting example sets that are of the type that should work. Table 3 provides one such example set. This list has been divided into several major categories; swarm behavior, resource ethics, community activity and understanding the human experience. These rules are not religious or moral laws, but rather a set of rules for daily behavior that could lead to sustainable society under the right conditions. In the emergent view, planners and government leaders would have to consider what conditions might be necessary to support an emergent transition rather than what policies or regulations they might employ. An example set of conditions is given Table 4. It is obvious that these example sets of rules and conditions are different than traditional broad policy and regulation statements.

Table 3: An example set of rules for individuals that could lead to an emergent sustainable society	
Activity in a swarm	• more is different, as many people as possible need to be engaged in pursuing a sustainable lifestyle • individuals need to be active and visible as they interact with other people

	• watch and learn from your spheres of contacts; family, friends, work, community
Resource ethics	• waste is food - don't degrade someone else's food • don't deplete ecological capital • avoid scarce items • enough is enough, don't use anymore than you need
Community action	• sharing increases value, generosity is more important than hoarding • trust that resources will be available when you need them from your community
Value different time and space scales	• learn to see the big picture and the long time scale but act immediately • think globally, act locally • invest at low returns for the long term
The human experience	• should include some uncertainty and challenges • each of us should contribute to the greater good through our individual actions

Table 4: Example set of conditions that may be required to promote individual action from Table 3.
The society needs to be pluralistic and democratic and needs to value both the individual and diversity.
Citizens need to be aware of the problem of environmental degradation and motivated to achieve sustainability.
Individuals need to have intellectual capacity and thinking tools to deal with a more complex society. This would include a broader range of metaphors and heuristics. Individuals and society also need to be able tolerate uncertainty and disequilibrium.
There needs to be opportunities for individuals to act on their beliefs. Incentives and subsidies could be used to create venues for these actions.
Individual attempts at moving toward sustainability need to be visible to the community.

One of the major differences between the centralized control and the emergent views is the underlying fitness landscape that is assumed. Top-down planning or directed change assumes that by specifying a goal and breaking that down to objectives and then identifying specific that will ultimately lead to that goal. Emergent behavior does not assume that humans will necessarily know the path to a goal ahead of time. The landscape in highly complex systems can become "squishy" in that it deforms with each movement. Emergent behavior relies on a large number of trials to explore the landscape. Top-down policy and regulation approaches try to use indicators that are easy to interpret, valid, and the results provide motivation toward some solution (Chambers et al. 2000). Simple sets of indicators that have these characteristics would also assume a smooth landscape with no local optima. Undirected and directed changes have different barriers (Arrow et al. 2000). Undirected change can be inhibited if all actions are equally rewarded, i.e. a flat fitness landscape. Individuals or subgroups won't be able to detect if they are moving toward a solution on a larger scale. Directed change can be inhibited if the group has an incorrect view of the underlying fitness landscape, in particular if there are local optima, individuals and subgroups will have trouble staying on the planned course when there are short-term losses and loss of fitness.

We will probably have a choice between top-down, emergent, or some combination. Regulatory structures, built from the top down, may require support from emergent processes, grown from the individual up. Daily and Walker (2000) argue that "strengthening national policies on the environment may well achieve nothing - on its own - given the very limited ability to enforce such regulations in many regions of the world" and that the transition to sustainability will require involvement at a wide range of scales and diverse contributors. In their view this contribution can be facilitated by private-sector involvement. In another study, public support for environmental protection policies and expenditures is dependent on cultural factors at the level of the individual citizens' values (Inglehart 1995). His research shows that individual's attitudes toward the environment "are only one symptom of a much broader process of cultural change that is transforming not only attitudes but much of human behavior. It is reshaping orientation towards work, fertility, and consumption patterns that affect the environment directly - " . In this cultural transition, some portions of the individuals in the society are shifting to postmaterialist values and this is having a direct effect on environmental protection. This is a good example of an emergent process linked to and supporting policy. One aspect of planned development may be crucial for an emergent transition, the well-planned urbanization of human population. Cities start as centers for protection and commerce but as they mature an information processing behavior emerges (Johnson 2001). Global urbanization may actually promote, rather than retard, the transition to sustainability. Including emergent systems into our views will increase the flexibility with which we address the challenge of attaining a sustainable future.

16.3 Setting up the conditions in which sustainability might emerge

Pluralistic descriptions of sustainability

There are multiple views that help us understand sustainability. I will just describe three views that are commonly used in environmental science and economics. First, we often describe the locus of real sustainability as the intersection between ecological, economic and social factors. Second, the strong view of sustainability is that natural capital is a privileged form of capital. Third, we can see how we are doing by using "triple bottom line" accounting. Although all of these views, and others, help us illuminate the connections between the different aspects of the total system.

Adopting a complex vision

The complex vision states that sustainability will be an emergent state that arises from the interaction between multiple factors. This vision of sustainability can only be understood by studying these interactions

In addition to the emergent complexity it may be that the only way to reach the sustainable state is to adapt from previously complex and nearly sustainable conditions. Alexander (Book 2) claims that the only way to develop the required amount of complexity to regulate a complex system is for it to unfold from within. This is similar to Ashby's Law of Requisite Complexity, where he claims that a regulatory system has to have a similar level of complexity as the system being regulated.

In short, the "extremely difficult path to sustainability" requires that we will have to grow embedded control systems from within. This means that we will have to establish economic, social and ecological systems that are regulated from within and are almost sustainable and then fill in from there. The "extremely difficult path" scenario doesn't allow any short cuts by wise, lucky or smart governments. We can only work our way through this, not think our way out of a problem.

Embracing the path down

Another twist to the "extremely difficult path" is that this will probably happen while the simple economic base is shrinking. Odum and Odum (2001) describe this as looking for a "prosperous way down". The resiliency folks describe the omega and alpha phases of a cycle, where resources are released and then organized to be able to be exploited in another turn of the cycle.

16. 4 Conclusions

Combining the complex vision, the "extremely difficult path" and the path down might seem rather pessimistic. These negative aspects surround an extremely positive kernel at the core. It is not an option to depend on government to solve the problem.

Multiple Perspectives V4.2

When the appendices are available, they will be posted to the web at:

http://www.johnrueter.com

Multiple Perspectives V4.2

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