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## Chapter 10: Games


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# Preface

***Authentic problems need integrative solutions.***

Authentic problems have many dimensions. This means that the information and skills that we need to address environmental problems don't come from studying just one discipline. Academic disciplines are great for aquiring new knowledge. Studying several disciplines and applying these to environmental problems is a start. However to generate the new ideas that we will need to address our current environmental problems, we will need to consider many different aspects of the problem simultaneously and let all of those ideas mix around in our heads before we make decisions. This approach is an integrative approach to environmental problems.

***Our values play a crucial role in what and how we learn.***

We learn by picking up some intellectual tools (formally or informally) and using those tool sto make sense of data or information. This process of learning also depends on what we value. For example, if you value biodiversity then you may learn a method for classifying species depending on their ability to survive. You have chosen to study wildlife and are using tools to understand which species are most threatened or endangered. Our values play a big role in what we choose to pay attention to and how we actually learn.

***Understanding environmental problems is challenging.***

To really understand an environmental problem means that we know what action to take next. There are many challenges to this level of understanding. First, we need to know stuff about the problem. We may need to be well versed on facts and concepts relating to the problem. Second, we have to have intellectual tools that allow us to think and process this information. After that, we need to have some confidence that the problem is worth solving and that what we are doing is going to help. Having confidence that you are doing the right thing is not the same as being confident that you are right. This book will help illustrate how approaching a problem from many different perspectives and holding that information in your head is the right path, but it may not lead to any immediate correct answers. This leads to ambiguity and uncertainty that can erode our personal confidence. The antidote to this self-doubt is to develop an optimistic and pragmatic stance. With this stance, you are willing to work on problems and let the ideas and questions ferment until the time is right.

I am using this book in a course that works with non-science majors to develop habits of mind to address environmental problems. First we discuss ways to characterize environmental problems that will later help determine potential approaches (Chapter 2). Second we learn several tools to address these problems (Chapters 3 through 10) . I have collected powerful tools from a range of disciplines that can be used. Third we examine different structures for solving environmental problems (Chapters 11 - 17). Finally, we examine the information, tools and problem solving approaches. In real situations this would be much more iterative and interactive, but the first time through you need to see how all the pieces fit together.

***The landscape for environmental problems is changing.***

When I was in college there were "solutions". For example we actually thought that "the solution to pollution is dilution". Then later in my life I was supposed to be a scientist and the point of science was to identify the problems and "pose the critical questions". Now after many years in the field, I feel that the role of science in environmental problems is to rigorously search for creative approaches to problems. The emphasis has shifted for finding solutions, to looking for the right questions, to using the scientific method to look for creative ways to decrease the impact or humans on our planet. This book describes tools and approaches that can be used in this optimistic and pragmatic frame of mind.


# Chapter 1. Introduction and Overview

## 1.1 Environmental problems need new types of solutions

We all share our environment. We are all responsible for the damage. We should all be involved in solving these problems. By "problems" I mean any situation in which the environment could improve. It could improve because the ecosystem and other earth functions work smoothly. Or, it could improve by providing humans with the same level of services and goods with less impact. We observe and measure processes in the environment, such as tree growth or fishery production, to understand the first type of problem. However, we need to understand how humans use the environment, what they prefer, and the impact of their use to address the second type of problem. Environmental problems include physical, biological and ecological processes and how humans use and value them. Values are central to discussing and understanding of environmental issues.

> *Definition of science: based on evidence that can be independently verified using rigorously tested methodologies to create knowledge.*

Environmental science takes a different approach to science than its sister disciplines such as biology and chemistry. We share the same general definition of science but we focus on problems and because problems entail values, we have to deal with human values right from the start.

Some scientists rigorously explore and build new knowledge that may have no known application to problems. This includes some of the outstanding findings in molecular biology, evolution, nano-chemistry or cosmology. By contrast, environmental scientists usually focus on an existing problem and use rigorous methods to discover new and immediately useful knowledge. At the other end of the spectrum, scientists take a scientific approach to existing problems with immediate applications of their new knowledge. Problem-based science uses different experimental design, methods and modes of analysis tailored to our needs. The difference extends to underlying goals. For example, in laboratory science the goal may be to run many replicates in order to get accuracy. There may be no reason not to run many replicates and controls under very specific conditions. In environmental science, particularly field work, unique circumstances and locations make it very difficult to even get limited replication. If you are studying a high altitude lake, there just might not be many similar lakes around. The goal for environmental scientists might be to uncover a pattern indicating or warning of an underlying problem rather than being able to run many replicates to prove the causes of a particular phenomenon.

## 1.2 We need to learn and think differently

Many environmental problems are complex. There are many factors that interact leading to outcomes dependent not only on the factors interacting but the landscape shape as a result of those interactions. People interact with the environment to get resources and in the process change the very nature of how resources are obtained and used. For example, humans cut down trees and in the process change the local landscape and weather necessary to regenerate the forest. These complex interactions may not have any direct cause and effect relationships. Instead, there are multiple factors and a patterns of interaction. In order to study these problems we need to think differently. In order to solve these problems we need to act differently. We must examine complex problems from different perspectives. We can probe and describe the problem's features employing different intellectual tools. For example, we might study a polluted stream by descibing the water flow, measuring chemical input rates, assessing impacts on fish, level of uncertainty, and then exploring management approaches to reduce pollution. This information from multiple disciplines could be used to identify the problem. However to look for solutions, we will have to integrate what we know and come up with new ideas. We have to go beyond just critically analyzing the problem into the realm of generating new ideas. This book provides a framework for making observations from multiple perspectives, holding all of these in your head until you try to make a decision about what to do. The framework's first part is to intentionally examine problems using different methods. These methods range from describing the scale of the problem to creating accounts and indexes (Table 1-1). Each of these methods provides some different information.

Table 1-1. Eight tools to explore different perspectives of environmental problems.

| Chapter | Activity<br>Tools |
|---|---|
| Chapter 3: Patterns | Examine the predictable components<br>Describe mechanisms as “likely” |
| Chapter 4:Scale | Examine the range to time and space<br>Create a Stommel diagram |
| Chapter 5: Networks | Examine relationships of all kinds<br>Draw a network diagram, calculate metrics |
| Chapter 6: Stock and Flow Systems | Follow matter or energy<br>Draw a visual model for a system |
| Chapter 7: Accounting and Indexes | Examine categories and ratios<br>Set up an accounting decision cycle |
| Chapter 8: Risk and Uncertainty | Differentiate between risk and uncertainty<br>*** |

| | |
|---|---|
| Chapter 9: Values and worldviews | Follow how values lead to worldviews<br>Differentiate between five major worldviews |
| Chapter 10: Games | Examine decision criteria<br>Set up a game square – against other people or nature |

Example 1: "Tragedy of the Commons" The so-called "tragedy of the commons" is used to demonstrate the idea that individuals will use resources to meet their own needs even if it means degrading a common resource that could be more productive if managed more thoughtfully. This example stems from grazing sheep on common land and it was to individual farmer's advantage to graze more sheep than the land could support sustainably. I have seen this example presented many times as if it really is a tragedy, i.e. a forgone conclusion that humans will pursue their own individual interest above the common interests of the community. These are analyzed as if they are one-shot interactions and the "prisoners' dilemma" metaphor is introduced. First of all, research on common pool resource management by communities shows that almost all of these are managed by community-based institutions (Ostrom ****). Secondly, invoking the prisoners' dilemma from game theory is a critical look at this problem, not a generative look. If we want to know why a particular commons was over-exploited, this might be valid. But if we are looking for solutions (as many authentic communities are), we can integrate the information we get from the games approach along with stock and flow systems to set useful guidelines for livestock management such that the common grazing land can be used sustainably and for the communities best interest as a whole.

Example 2: The precautionary principle The precautionary principle is a decision criteria that states when you don't know the outcome you should take action to avoid the worst outcomes. This principle is also interpreted to mean that if you don't know the outcome of an activity, then you shouldn't do it. As stated, this principle seems to provide a simple guideline for cautious action. This often leads to paralysis in complex and wicked problems (see next chapter). In an integrative approach we would explore a problem from many different perspectives in an attempt to discover new ways to address the problem. Rather than shying away from action in complex and wicked problems, we would be drawn to the complexity like moths to flame. *** more here ***

## 1.3 Importance to you

Environmental science addresses authentic problems that require mulitple disciplines and management approaches. All of the problems have issues with information, control and values. Is there enough information available to understand the problem and know what to do or is there a large amount of uncertainty? Do we have the skills or ability to actually control the situation and apply solutions? Are the community values in alignment or is there disagreement between individual or parts of the community on what they want to do? Not only are environmental issues such as global climate change and loss of biodiversity important to our civilization as a whole, but the pragmatic appraoch taken by environmental science can be a useful philosophical basis for you as an individual. In order to solve the big problems our society needs to deal with mundane, every-day problems. Climate change is linked to fossil fuel use; fossil fuel use is linked to transportation; transportation provides options for education and food provisioning. All of these are inter-related and it will take a robust "philosophy of life" to deal with them.

Some of the examples and issues in this book will highlight how knowledge, skills and values are inter-related at the levels of individuals. Simply, the knowledge you aquire is related to your intellectual skills and that is motivated by your basic value system.

## 1.4 Overview of the book

This book has four sections. The first section deals with describing environmental science and why we use multiple perspectives (this chapter) and a description of major problem types and approaches to solving environmental problems (Chapter 2). Problem types are characterized in three dimensions, 1) the knowledge or uncertainty, 2) the level of control that can be brought to bear on the problem, and 3) the alignment of community values or conflict that might exist over possible solutions.

The second section of the book presents eight approaches (Table 1-1). Each approach is described as a method to examine a problem. Applying a particular method to a problem has heuristic value, i.e. it tells you whether that particualr approach gets any traction with the problem at hand. Each approach can lead to more sophisticated applications and analysis of problems. The approaches are illustrated by a graphical exercise. These graphics should help you to engage some of your emotional and creative skills.

The third section presents approaches for addressing environmental problems that are matched to the knowledge, control and values attributes. For example if you have abundant information, ability to control the implementation of a solution and everyone agrees, you can use optimal project management to find the most efficient outcome. However if there is a high degree of uncertainty, the situation is out of your control and no community consensus exists you might only be able to start a discussion around possible paths by using possible scenarios. These are the two extremes and there are intersting approaches in between (Table 1-2).

Table 1-2. Range of approaches for addressing environmental problems Approach

| Chapter | Problem solving structures |
|---|---|
| Chapter 11: Optimization | Efficiency is a major contributor to environmental solutions but has limits |
| Chapter 12: Institutions | Organizations and rules that promote cooperation |
| Chapter 13: Scientific Adaptive Management | Management efforts that include hypothesis testing |
| Chapter 14: Scenarios | Creation and review of plausible outcomes |
| Chapter 15: Diversification | Using a portfolio of approaches to reduce risk |
| Chapter 15: multicriteria decision framework | Considering and negotiating to meet diverse needs |
| Chapter 16: Innovation by design | How to promote innovation toward environmental solutions |
| Chapter 17: Environmental Entrepreneurism | Using business solutions to environmental problems |
| Chapter 18: Project evaluation | Setting goals and feedback mechanisms to improve performance |

The final section is the last chapter that deals with evaluation of outcomes. All of the methods and approaches are ways to get started. Real environmental problems will change and require constant adjustment of monitoring and management. Chapter 18 explains how to continually revisit and adapt. For example, you might start out with a serious problem and your only option is to develop scenarios until you can build support. That might lead to enough community support of consensus to employ some experimental techniques that you could follow rigorously with scientific adaptive management. Finally, after years of successful scientific adaptive management you may be able to switch to a set of diverse management tools that cover the possible outcomes and reduce risk of failure. The only way you can move along this path toward more direct solutions is by continual evaluation and adaptation.


# Chapter 2: Problem Types and Approaches

## 2.1 Three components of environmental problems

We face authentic and serious environmental challenges. Depending where you live, the set of problems can differ. In the United States our problems are generally chronic and result from high levels of consumption. Most other developed countries are similar. On the other extreme, poorer nations face acute environmental problems requiring immediate attention. For example, several billion people don't have access to clean water sources because of poor municiple water supplies or pollution or both. In these poor countries water necessary to produce food conflict with the demand for human consumption and hygeine. Even with this seemingly big gap between the chronic problems in the West and the accute problems elsewhere, we can identify three main components:

- Knowledge: the degree of knowledge vs. uncertainty,
- Control: the degree to which we can control the environmental and attempts at solutions
- Values: the degree to which the community agrees on what should be done and the distribution of costs and benefits across the community

Scanning problems for these dimensions of KCV (knowlegde:conrtrol:values) will help inform our decision on what strategies to employ.

**Knowlege vs. Uncertainty**: Even thought we have an increasing amount of information and knowledge at our fingertips, the ratio of knowledge to uncertainty is the important dimension to problems. We understand some problems very well. In some cases simple cause and effect relationships dominante. For example, water depletion results from inefficient irrigation. Using less water to grow crops saves water, streams, energy and possibly even money for the farmer. However if the goal of the farmer is to make money rather than food, i.e. it is a commercial enterprise, then additional sources of uncertainty must be considered. If the farmer has more efficient methods to water crops, the farmer may decide to grow higher cash value crops that consume more water. The uncertainty about crop water use and the farmer's choices make this a much more complicated question. In addition, what if the farmer has to consider what his neighbors and competitors are doing with their irrigation and crop choices? There isn't always a simple answer based on just knowing the facts.

It seems paradoxical but we can also create higher levels of uncertainty by learning more. Homer-Dixon (****) calls this the "ingenuity gap". The application of knowledge or energy to any problem can actually create more uncertainty. In some cases, humans apply so much energy to an environment that it becomes unstable and indeterminant (Adams ****). A good example of this is the overwhelming use of power in warfare. The environmental damage caused by these forces disrupts the social, economic and ecological systems to such an extent that it is impossible to predict how they will respond. Obviously war is a major environmental problem but we don't have to look to the bad side of humanity to see how new knowledge crreates uncertainty. Refrigeration systems using chloro-fluoro-carbons(CFCs) is a good example. Refrigeration is used to protect food and medicine from spoiling. Good refrigeration systems are a great publich health asset. You might think that making refridgeration better would be a good thing. CFCs were discovered by just a few scientists and then rapidly applied to improve refrigeration. But as we all know now, those CFCs also lead to chronic effects in the atmosphere and the depletion of ozone. In this example, a discovery by a few scientists created uncertainty and it took many years and hundreds of scientists to solve.

Chapter ** contains tools that help assess the levels of risk and uncertainty.

**Context and control**: Management solutions to environmental problems require some contrrol over the environment and humans. Hardscape or "grey" engineering solutions are all about control. Structures are used to harness and control environmental processes to meet the needs of humans. Roads, dams, buildings, and powerplants are all examples of hard infrastructre that is able to control many environmental factors and provide a solution. More recently, large scale "green" projects have been used to address some environmental problems. Green solutions rely on ecological structures and functions that aren't as easy to control but might have additional benefits. A good example of this comparison is for cooling water from industry. The "grey" solution is to build a cooling tower that can be run very effectively and engineers know how to operate. The "green" solution is to construct a set of ponds or wetlands that cools the water as it flows through and provides habitat, recreation and aesthetic benefits. These wetlands are less controlled. ***

Another aspect of control is human actions - major source of uncertainty

**Values:** Simply- humans are a dominant force on the planet and unless we consider what people want to do and what they value, environmental projects will fail. We can make objective statements about values, i.e. we don't have to judge the validity or integrity of those values.

There are important aspects to values: distribution of individual values and coherence between individual and community values. The range of individual values is wide but these can be categorized into about worldviews. Worldviews are self-reinforcing systems of values, analytical tools and knowledge that are very useful to understanding different groups views on risk, responsibility, and the robustness of nature. Another crucial aspect of values is whether the people benefitting from the project are the same or different from those who are being impacted or paying for the project. For example, air pollution from commuter traffic negatively impacts urban children and yet they get no benefit.

## 2.2 Four problem types

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 or incentives or just pass a law, then everything would be fine. There are certainly some cases where more information could be valuable. However there are many other environmental problems that either can't be helped by more information or where the money needed to acquire new information would be better spent solving the problem. People also have different ways of valuing an environmental condition: where one person may see a dangerous mosquito-ridden pond, another may see a bio-swale that cleans up road runoff. Many times it would cost more to study the multiple possible consequences of our actions than it would to just avoid them. For example, should we dump a new type of chemical that we know is toxic into streams? Experience has taught us 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 categories (Cunningham and Sato 2001) (Table 1-2). Some problems might fit into one category easily but others problems might overlap these categories. 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, eliminating lead additives in gasoline or house paint is a simple problem with a solution that is good for everybody.
>
> **Information Demand Problems:** Though extensive information may be needed to decide what action should be

taken, 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 require that we appeal 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 with additional information, the possible solutions seem to have uneven benefits. Wicked problems also change because as more information becomes available, individuals' 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 other options (i.e. fossil fuels, nuclear, biomass, and others).

Table 2.1 Types of environmental problems and decisions (adapted from Cunningham & Saigo 2001). The most likely approach to a solution is listed for each category.

| information demand | alignment between costs and values | |
|---|---|---|
| | good | poor |
| simple | EASY<br>regulations | Community Value<br>community rules |
| extensive | INFORMATION<br>more research | WICKED<br>scientific adaptive management and political processes |

Later in the book (Part 4) we will return to looking at actions that can be taken depending on the characteristics of problem. We will also revisit the idea of how multiple perspectives can suggest different solutions rather than a single approach, i.e. simple prescriptions. For example I will show that the idea of the "tragedy of the commons" is an overly simplistic analysis of the community value problem for sharing a common pool resource, and that once the complex paradigm is applied to include stakeholder preference diversity and spatial linkages (i.e. neighbors), the most promising solution looks more like promoting cooperation rather than imposing strict and broad regulatory control (as suggested by Hardin (1968)). This conclusion bolsters the importance of the second theme of this book, that it is a big mistake to apply simple solutions to complex problems.

## 2.3 Major types of management

Now let's look at a similar table that examines the types of approaches that are available to us as environmental scientists and managers. In this table, the dimensions are the degree of knowledge vs. uncertainty and the degree of control that can be exercised by managers.

Table 2.2 Approaches determined by the dimensions of control and uncertainty (From DOI – Adaptive Management Handbook)

| | **Sufficient knowledge** | **High uncertainty** |
|---|---|---|
| **High control** | Optimal Project Management | Scientific Adaptive Management |
| **Low control** | Hedging: multiple investments | Scenarios |

## 2.4 Approaches that are needed for all problem types

All of the problems that we address in environmental science and management probably need a combination of some innovation and institutional enhancements. Innovation is essential when we are working with complex problems because each situation is different and may be unique in some way. The innovation does not necessarily have to be some extremely creative, out-of-the-box invention. Most of the time the innovation can be supplied by combining current technologies and social institutions in novel ways. Even this relatively simple version of innovation requires support during the problem statement process and continued support through full scale implementation from institutions that are designed to deal with the trials and learning that comes from innovation. This will be addressed in more detail in Chapter 15.

Institutions are also required to manage projects and deal with all levels of public involvement. Some communities that depend on natural resources have highly developed institutional structures that allow for a fair and mutually beneficial allocation of common pool resources. Other areas might have developed strong top-down, command-and-control type methods to allocate resources. A comparison of these institutions and how and when each may be desirable will be discussed in Chapter 16. Chapter 16 will also address the institutional structures that are necessary for scientific adaptive management (SAM) because this is the proscribed management approach for many large state and federal projects. We will address the interplay between SAM and public decision processes, specifically the many forms of both democracy and consensus.

## 2.5 Problem solution structures

I have combined Tables 2.1 and 2.2 into one table that uses the three dimensions to indicate which problem solving approach is probably most appropriate. Each of the approaches will be described in a subsequent chapter.

Table 2.3 Problem dimensions and appropriate approaches.

| **Know-ledge** | **Control** | **Values Match** | **Approach (Chapter)** |
|---|---|---|---|
| L | L | L | Scenarios of plausible outcomes (14) |
| L | L | H | Innovation by design (16) |
| L | H | L | Environ-Entrepreneur (17) |
| L | H | H | Sci. Adapt. Manage. (13) |
| H | L | L | Multi-Criteria (15) |
| H | L | H | Diversification (15) |

| | | | |
|---|---|---|---|
| H | H | L | CPR institutions (12) |
| H | H | H | Optimal Proj. Man. (11) |

## 2.6 Summary

Taking action is part of the cycle of understanding. Choosing which approaches to employ when faced with complex environmental problems can be a challenge in itself. We can use the narrative or narratives that were used to pull information together from the multiple exploratory and diagnostic tools. These narratives are evaluated along three dimensions: 1) the degree of knowledge vs. uncertainty, 2) the coherence between individual and social values, and 3) an assessment of our ability to control the environment well enough to implement any particular solution. The outcome of this analysis will guide us to employ one or more of eight general approaches: guided innovation, enhanced institutions, optimal project management, hedging and diversification of approaches, multi-criteria decision analysis, forecasting with scenarios, scientific adaptive management, or environmental entrepreneurism.

# Chapter 3 - Patterns of Interaction

## 3.1 Patterns are the predictable components of the environment

As we observe or collect information, there are some behaviors that seem to fit and are predictable and others that are not. We are uncertain about the unpredictable behaviors but we can make casual or folk predictions about many things. Humans are extremely good at detecting patterns in data, music, the environment. Sometimes what we think we see is valid and other times it is not. Because so much of this is "built into" our thinking, it is actually a difficult task to take a scientific approach to the detection and description of environmental patterns.

Obviously, just saying you think you see a pattern is not sufficient. This chapter describes a method that we can use to detect, observe, model and predict what can happen in complex interactions. For us to study a pattern in the environment scientifically we must be able to:

1. collect evidence
2. that other people can verify with their own observations
3. using a method that can be tested in other situations

Most of the environmental problems we will examine fit into 3 categories. The most obvious cases are "cause and effect" situations. There is a driving factor that causes the pattern. More or less of that "cause" will lead to more or less of the "effect". Toxin pollution is a "cause and effect" situation. The second category involves complex interactions between many actors and/or processes that are all taking place simultaneously. The pattern that is created can only be understood by observing all of the interacting factors. If you take any of the factors away, you don't get the same pattern. A good example of this is the spread of disease. You need a population with a range of health status, some disease agent and interaction between the people. The number and history of the people make a huge difference in how the disease spreads. However, even with this complexity, we can describe the pattern of the epidemic, make predictions and do something about it. We can't predict exactly who will get sick, but we can predict the general rise and fall of the epidemic, i.e. the pattern. The third type of pattern is cryptic. This means that we can observe a predictable behavior but we can't collect observations or evidence of what causes it.

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

## 3.2 Detecting and recognizing patterns

The first step in understanding and responding to the environment is looking for patterns. Because humans are innately good at seeing useful patterns, we might take this activity for granted. However, we need to develop both a broader awareness of types of patterns and study 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.

Some patterns are the outcome from simple cause and effect relationships. These are easy to recognize and can be dealt with straightforwardly. If we know that there is too much pesticide going into a stream, there are many ways to decrease that input. But sometimes what seems like a simple cause and effect relationship may have very important internal interactions taking place. We need to look for and consider other mechanisms that could cause a similar pattern.

We don't have a infallible and rigorous method for searching patterns. Instead we can scan other mechanisms and patterns to see if they might apply. Although this may seem like a major weakness, our inability to systematically scan all patterns fits with the theme of this book: in order to really understand environmental problems you have to search for alternate explanations and solutions, using methods that don't provide the same type of information. I will illustrate how to use multiple explanations an example.

## 3.3 - 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.

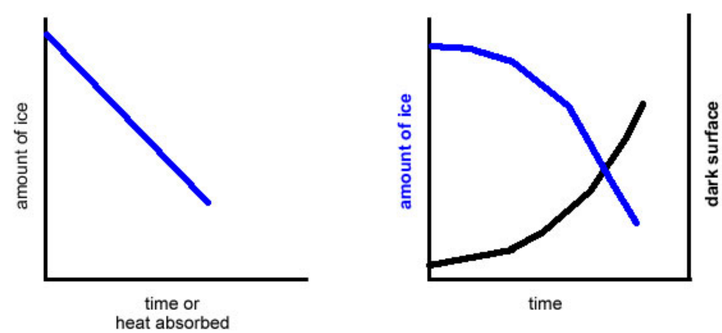



Figure 3-1. Ice melting rates in different configurations. A) ice melts as a result of absorbing heat. The absorption rate of heat is constant and thus the melting rate is linear with time. B) The absorption rate for the system changes as blacker surface is exposed, resulting in an interaction that changes 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.

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.

## 3.4 Learning to see more patterns in the environment

The architect Christopher Alexander developed an extensive framework for describing patterns (Alexander 1964, Alexander 2002). His work provided a language of patterns that allowed other architects and designers to discuss buildings and how people use them. For environmental patterns, 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 organic or natural patterns. Examining the natural world for biologically inspired solutions, called “biomimicry” by Bayrus (1997) is another example of a deliberate search of natural patterns that was very fruitful for engineering.

I have compiled a catalog of patterns that can be observed in the environment and may be caused by underlying complex interactions. 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.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 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.

Remember, scanning this catalog isn't a valid search strategy for proving any relationship, rather it is 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.

Table 3-1. 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).

Easily identifiable spatial patterns generated by: Banded vegetation – facilitation in 1D (NetLogo model) ILP – facilitation in 2 dimensions Forest mosaic (my-forest-fire.nlogo) Fractal watershed erosion or delta deposition Percolation of oil into soil (Netlogo) Swarms resulting in structures Swarms resulting in dynamic behavior, such as flocking Dunes

Dissipative structures that are the result of large energy flux Bernard cells River meanders Geisers

Temporal patterns Water pulsing in a sluice way Box-car effect on the freeway Logistic growth curve to deterministic chaos, chaos does not equal complexity

Phase transitions Time for forest fire to proceed through landscape – dramatic increase near threshold ILP (Reichart) O2 flux causing variations in DO (STELLA) Green-Desert transition (Sole') Social collapse – sunk cost model (Sole')

## 3.5 Characterizing patterns

When we observe a pattern, we can describe it to other people in three ways. First, you could draw or act out the pattern. In order to use this scientifically, you need to make a representation of the pattern. For example, if you see a pattern in the bark on the trunk of a tree, you need to be able to describe it so that it can be represented in other ways. You can't just cut down the tree and carry it around with you. Drawing, acting, singing and other performances are all very powerful ways to describe patterns but they are clearly disadvantaged in a digital information world. Representing a pattern in a format that can be digitally shared and searched is a key aspect of modern communication.

Figure 3.2

A second way to describe a pattern would be to compare it to other known patterns. The comparison could include details about how the known pattern is different than the one you observed. For example, you could say that the bark on the tree looks like a stress pattern that forms when you dry clay, but that the

**insert image of clay cracking **

Another example is to compare the branching pattern that we see in fern leaves to the pattern of streams in a watershed. The underlying processes must be very different however there is a striking resemblence. The brancing of ferns, trees, watersheds and many other patterns can be described using the fractals (Benoit ****). These descriptions have stimulated investigations on the underlying factors and a deeper understanding of branching patterns.

Figure 3.3 Fern and erosion pattern in ash deposit.**note - the erosion in the ash bed is not my photo -- needs to be replaced **

## 3.6 Generating patterns with models

The most scientifically powerful way to describe patterns is to demonstrate that you can generate that pattern with a computer program. For example, the branching patterns in different species of trees can be generated with a fractal model that only uses several parameters (length to the branch point and the angle at which the next branch takes off). Such simulation are useful in describing the pattern and also, as we'll see in the next section, for figuring out what to do about to the environmental problem.

Models are simplified descriptions of the world 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 that is based on birth and death rates. It is straightforward to measure birth and death rates to make the model and to work backwards from the model to show that the predicted population is consequence of those factors. But models of complex systems often loose that connection to observable mechanisms and this makes it even more difficult to explain the gross behavior in terms of 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.

Wolfram (2002) has described a "New Kind of Science" in which he uses rule-based cellular automata to generate 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.

Several patterns in the catalog (Table 4-1) can be generated using simulations that have very simple rules. The fourth column indicates the type of model used to simulate the pattern. These described in more detail and with links to on-line simulates in the appendix.

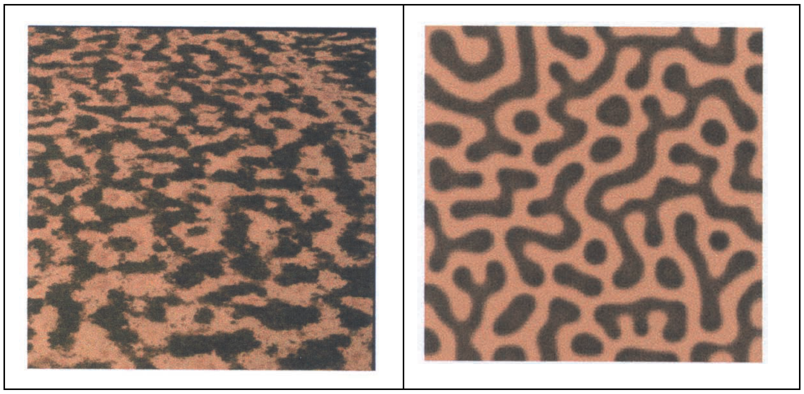


Figure 4.x An aerial photograph of the vegetation pattern in a xeric region of Niger (left) and a simulation of that same pattern created with a cellular automata (right). The simulation demonstrates that the lateral flow of water, accompanied by nearfield plant-on-plant inhibition and farfield promotion, results in a similar pattern. From Reitkerk 2002. *These images haven't been cleared for use.*

## 3.7 Describing the most likely explanation or model

Instead of trying to prove that one particular model describes a particular data set we can compare several models to see which is more likely. This approach asks the question, "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. This may seem like a subtle difference but this approach works well for us because we are trying to include as many explanations or models at the beginning and test them against each other. The language of this approach also goes with the theme of this book. We are comparing likely models rather than trying to prove that one model fits the data.

## 3.8 How do we take action if we are not sure?

As described in Chapter 2, two of the three key components of environmental problems (knowledge/uncertainty and ability to control) relate to the question of how do we proceed when we are unsure and what actions can we actually take. Most of the rest of this book will also deal with either multiple ways to describe environmental problems or structures for actions that might be able to address those problems. I don't think there is ever any time in this book where I say that any particular problem can for sure be solved for sure with a particular approach. So the question really is, "how do we proceed even though we are unsure?" with the assumption being that we are going to take some action.

The best available scientific approach is to use models. These could be simple, what-fi scenarios or more complicated computer simulations. For an observed set of data, we would create several simulations that match the available data but would have different underlying mechanisms. These simulations could be to generate predictions that are either ambiguous or conflicting. A simple example of this is to compare exponential and sigmoidal models for the growth of the population (Figure 4-2) and to then predict at what point the predictions diverge by more than 10%. Then we can use; 1) isolated experiments, 2) specifically crafted and intentional disturbances

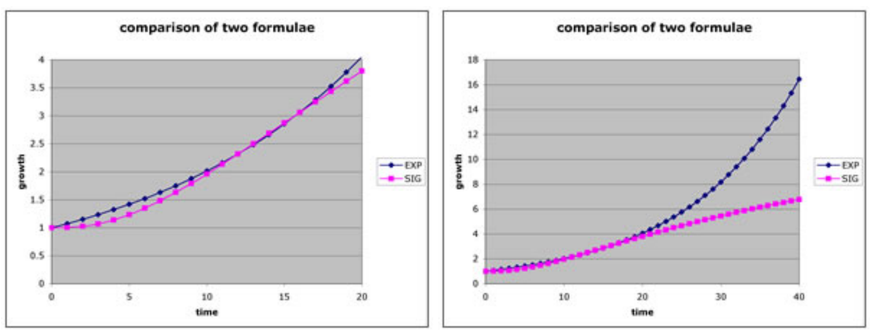



Figure 4-2. Comparison of two growth models. Both figures have the same underlying equations generating the curves, the only difference is that one "simulation" runs twice as long. In the figure on the left, both curves are incredibly close, within the size of the symbols for many points. Only after 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.

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. 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 difficulty justifying the change in their work schedules when there was an exciting breach of a levee that led to an unexpected perturbation event in the lake they were monitoring. The organization’s budget was closely controlled to meet the monitoring goals and there was not enough slack to allow unplanned monitoring. Eventually a compromise was made and valuable data was collected, but it shows that you can't just expect to be able to explore some of these surprises. Scientific adaptive management design (as described later in Chapter 18) tries to build in dealing with novel or unexpected results into the project (and the budget).

## 3.9 Some patterns are real but 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 natural 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. 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). These type problems have been described as "spiraling out of control", a "vicious spiral" or "crossing the tipping point". 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** there are positive feedback processes (such as might be caused by increasing temperature releasing more CO2 from tropical soils or methane from the tundra), **THEN** it will be much easier and cheaper to make an incremental reduction as a preventative measure now than to repair extensive damage 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. That means that 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 at a crucial threshold of habitat fragmentation the biodiversity takes a huge loss. 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 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.

## 3.10 Two examples of employing patterns to address an environmental problem

### *An illustrative example: Pollution levels in a stream*

Let's compare two ways to examine the amount of pollution that is introduced into a stream by a point source. This is an over-simplified example to illustrate the difference between a deductive and inductive approach. The deductive approach would start from a set of known laws and apply them *a priori* to hypothesize a cause and effect relationship. The inductive approach would be to collect observations and then to look for patterns to expand our understanding. Both of these approaches are valid and powerful types of science.

***Deductive approach - starting with the laws***

The law of conservation of mass 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.

***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.

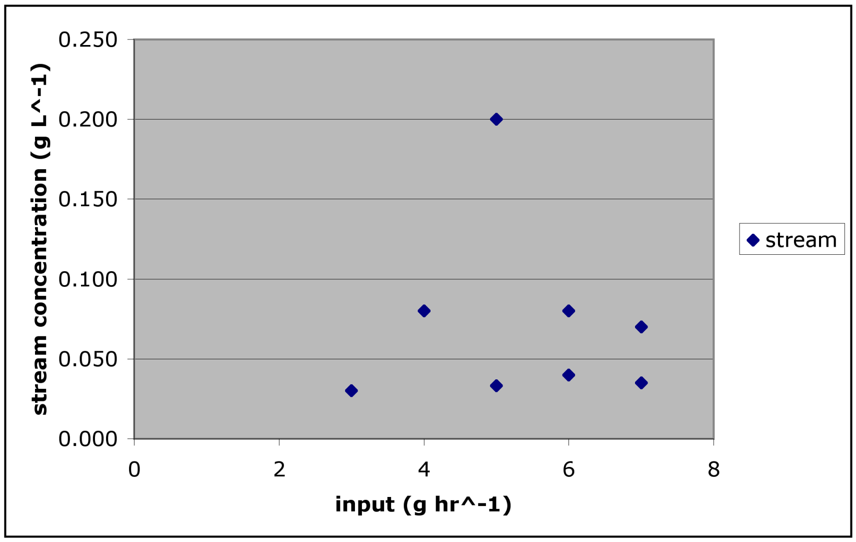



Figure 4-3. Data from Table 3 plotted as the stream concentration related to pollution input rate.

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**<br>**g/liter** | **mass of pollution transported by the stream**<br>**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.

***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 researcher 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.

### *A more complex example: 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.

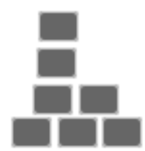
Dropping sand grains one at a time onto a pile is one example of the complex behavior that can arise from a very simple set of rules. The rules are that:

- 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:

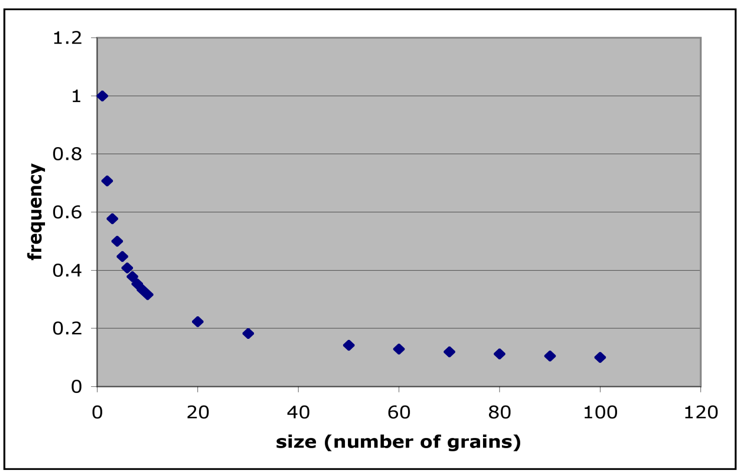


Figure 4-4. Frequency of landslide as a function of the magnitude of the landslide. There are very few large events, but many small events.

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

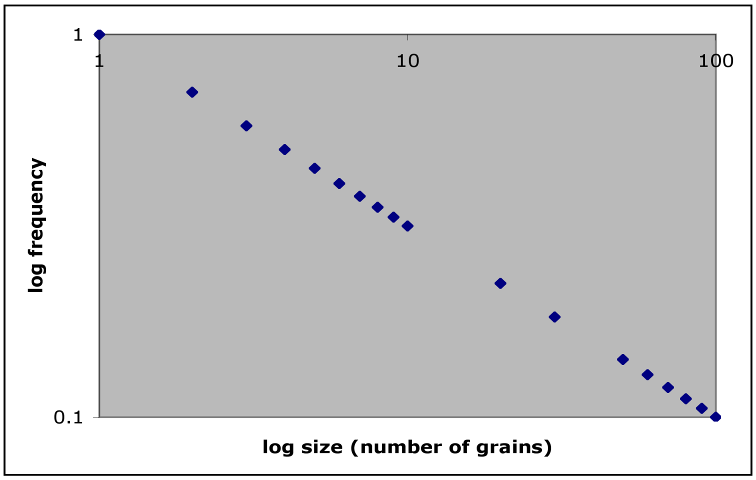



Figure 4-5. The same data as in Figure 4-4 plotted on a transformed set of axis: log of frequency vs. log of the size of the landslide.

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).

## 3.11 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 themselves 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 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 |

***Metaphors are often abused in public discourse***

Invoking powerful and scientific metaphors can be dangerous. I call these "fractured metaphors", when only part of the system is used. People employ these to provide the imprimatur of science, complexity, or "natural-system-ness" to descriptions as part of their argument in support of their approach. Some of the most abused examples are:

Describing an organization as a tree with all the branches deriving their support from the trunk (i.e. central organization). This image seems to lend credibility to the trunk as an important part of the tree when in fact it is just a conduit between roots and fungi in the soil and the branches and leaves.

Describing a competitive, winner-take-all process as some sort of natural selection. The invocation of Darwinian natural selection makes this seem like a tested and efficient process, when in fact natural selection relies on built in processes that create diversity in the gene pool.

Describing an industrial process as “eco-industrial” because there are significant internal processes. It sounds organic, environmentally friendly and efficient. But many of the examples are violating all laws of ecology by concentrating waste toxins against gradients (such as fly ash or sulfur by-products of coal consumption).

## 3.12 Summary

The environmental/agricultural philosopher Wendell Berry (1981) says there are three ways to act on a problem: first - do something that doesn't actually solve it, second - push the problem somewhere else, third - solve the problem "in the pattern". It turns out to be very difficult to solve the problem "in the pattern" because many of the crucial problems turn out 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.

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# Chapter 4 - Scale

## 4.1 Appreciation of scale helps you observe

We are told to get out and observe nature and our environment. Louv (****) extols the benefits to children for just being outside mucking around. Stilgoe (1998) tells us that there is magic outside, if we just go out and look with a careful eye. But, although it is fun to play or wander around, we need to have more direction or purpose than that. One method to do this is to direct your attention to making observations about the scale of the objects and processes around you. Whether you are observing the context for a problem or getting familiar with a new environmental setting, you should direct your attention to determining: 1) the size and relevant historical period for the setting, 2) the size and spacing of the objects, and 3) the rate and magnitude of the processes that are taking place. Of course all of these will be rough estimates but it will get you thinking about many aspects of your surroundings that you might have missed.

This chapter presents three different levels of addressing scale: descriptive, analytical and generative. The first task is to be able to describe the texture and relative sizes and process rates. The second level is to analyze the relationships between these objects and rates especially to look for processes that take place across scales. Fast and slow processes have very different effects on environmental problems and we will revisit this when we discuss resilience in Chapter 5. The final level is to use what we have learned to generate new solutions. The example used here is to design “scale effective” solutions in which our solution to the problem matches the scale. This is the approach taken by the proponents of “smaller is beautiful” solutions (Schumacher 1977).

We have many tools at our fingertips (literally) to help make observations across scales. Before I visit a place I pull up maps and satellite images of that area. I can drill down to see what's there. It's like having my own drone, which by the way are getting cheaper and easier to use for all sorts of environmental applications. I can also look at historical photos of areas through Google Earth or through geo-referenced archives. I can get weather records, building records, a whole wealth of data on any particular spot. Finally, if I need to I can place time-lapse cameras around to get a sense of what's happening over a day or week. All of these tools give me a good start to observing different time and space scales.

## 4.2 Create a Stommel diagram

A Stommel diagram is a map of all the objects and processes in the dimensions of time and space, rather than their location. The purpose for creating this diagram is to make you look for objects and processes that occur at all range of scales. If you have a big gap in your Stommel diagram, then you should probably look some more.

***Determine the extent.***

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.

***Describe the texture of the physical objects***

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.

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 (using by color). The percent of different vegetation/color types found is given in Figure 3.

a.


b.

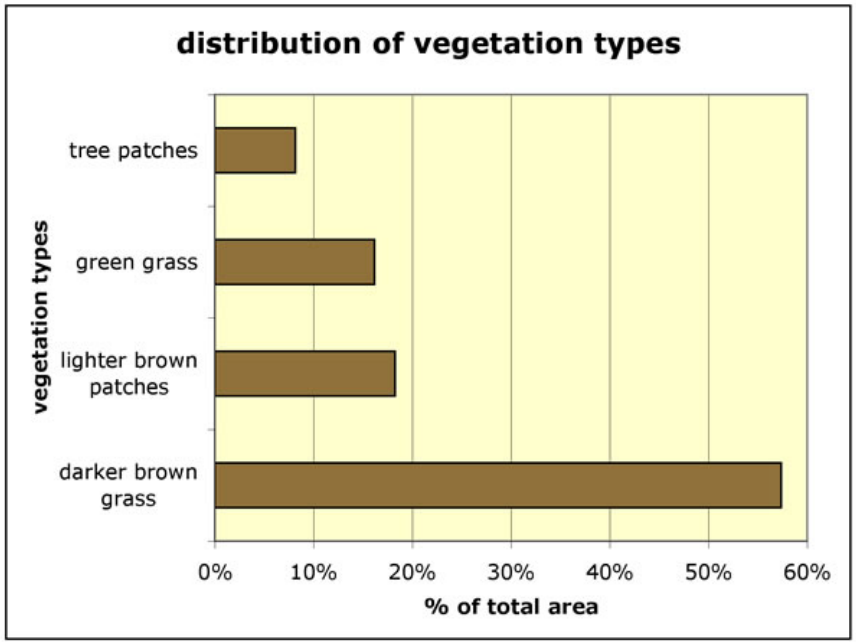



Figure 3 –Texture of a landscape. A) An image from maps.google.com This image is from Maps Google (Google - Imagery ©2010, USDA Farm Service Agency, GeoEye, State of Oregon, Map data ©2010 Google). The percent of the different colors was analyzed in the photo using Photoshop. B) Four categories of land cover as estimated from color and pattern.

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

### *Estimate the rate of processes*

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.

At first these estimates are gong to be very rough. 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 that need to be represented on the graph.

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)

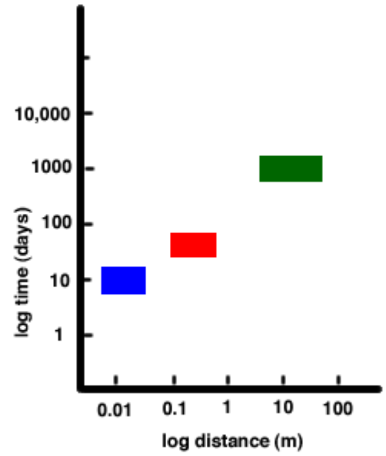



Figure 1. The green is trees, red is the birds, and blue is the insects.

You will see more examples of Stommel diagrams in this text including in Appendix 2: Scale Case Study.

## 4.3 What are the cross-scale processes?

Understanding cross-scale processes takes more than just measuring over a wide range of values. We have to look at how processes are connected. In a way, this is an example of using multiple perspectives (time and space) within one of this text's perspective tools. The question is how any particular process connects to other processes at slower or faster rates or at smaller or larger space scales. For example, a river moves the bulk of the water out of the watershed every day but it also shapes the steepness of gullies over many years. On the short time scale excess erosion can be bad for the fish in the stream. However, the slow process can result in erosion and trees falling into the stream. The woody debris in the stream can maintain aeration. So over the long period, erosion can lead to healthy stream for fish. Erosion may not be the real problem over the longer time scale. Maybe the problem lies with watershed management, forestry practices or changes in weather. Examining cross-scale processes helps identify these linkages.

Other examples of cross-scale processes are:

- soil processes recycle phosphorus very quickly, nitrogen at a moderate rate and carbon very slowly and yet all of these are tied together in plant growth
- many small and short forest fires may promote biodiversity and the long term health of forests
- occasional disturbances can promote the long term health and resilience of those ecosystems

## 4.4 Human impacts on cross-scale processes

Many environmental problems come from human activities that disrupt healthy cross-scale interactions. Some activities, such as building gigantic highways, cause fragmentation. Bits of otherwise healthy ecosystems are stranded away from connection to the population genetic pool or flow of resources that are needed. Some activities, such as how we use large amounts of energy, result in stressed areas that are homogenized from dissipating this excess energy. You can identify these two major sources of environmental problems by looking at the cross-scale processes that are being disrupted.

***Look for fragmenting***

One of the major environmental impacts of humans 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 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 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)

***Look for homogenization***

Edge effects, dissipation zones and human energy intensity are related concepts that describe the borders between human and natural areas. Consider a 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.

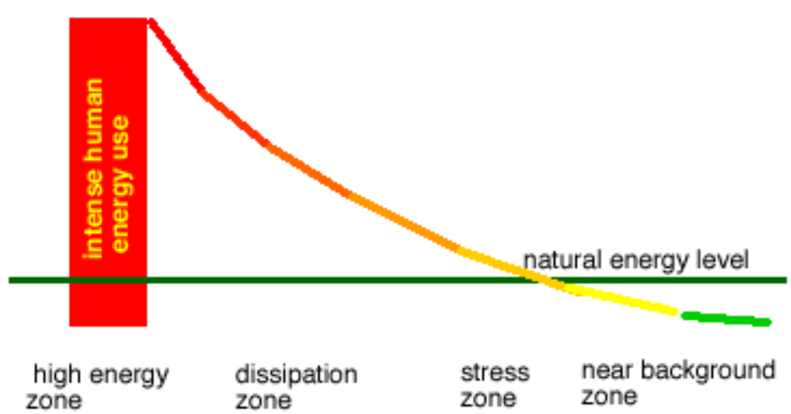


Figure 5. - Dissipation zones based on relationship to natural levels of power density.

One of the consequences of modern industry is that processes have been concentrated to allow for higher mechanical and thermal efficiency. This concentration leads to high energy densities at particular locations. Areal power densities for common industrial activities 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).

## 4.5 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 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), the working unit is replicated many times. 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.

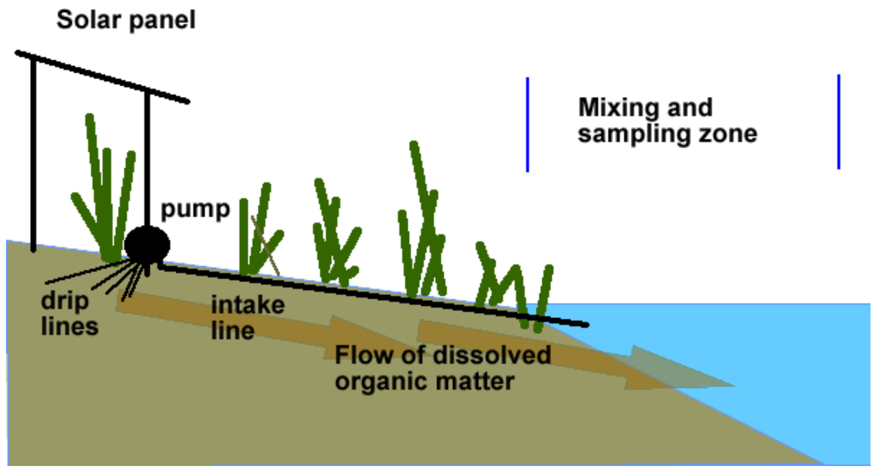



Figure 5. A schematic of using solar energy to pump water through a constructed fringe marsh.

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.

## 4.6 Why this is important to you

***Looking at the big picture and the details***

How can the devil be in the details and you need to look at the big picture

***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)

## 4.7 Summary


# Chapter 5 – Network Structure and Metrics

## 5.1 Structures lead to types of behaviors

The purpose of the "network" view is to look holistically at an environmental problem. Later, in the "systems" view, we will brake down the problem into sub-models and express those using narrowly. 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 specific vocabulary.

The "network" view is very useful for systems that have a medium number of objects that interact in 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. To demonstrate this, 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 additional insight into the problem to the dynamic systems approaches. 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. This view 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 or edges - 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.

## 5.2 Node and arrow network diagrams

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 5-1).

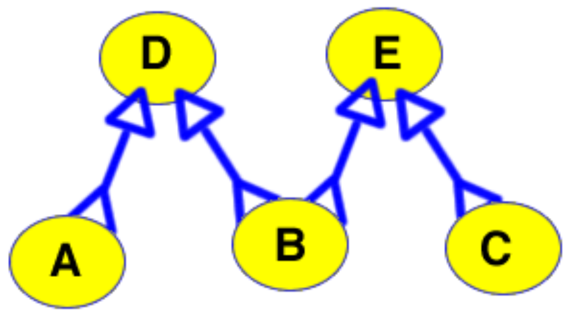



Figure 1. A node and arrow network diagram for a food web with five participants. "A" and "B" can pass energy or materials on to "D". "B" and "C" can pass energy or materials on to "E". The focus in the network view is on the interactions, in this case there are four unique interactions, AD, DB, BE, 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.

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.

## 5.3 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 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.

## 5.4 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.

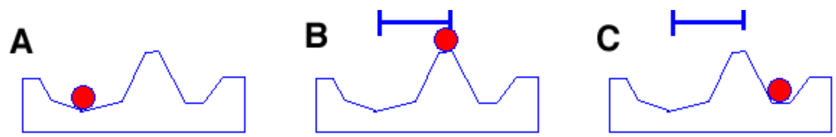



Figure 5-2. A common metaphor for the resilience of a system. Figure A is the stable state. Figure B shows how far you need to move the ball and yet have it still roll back to its original state. The bar represents the resilience of the left basin (or attractor). Figure C shows that the system was pushed to far and moved to another stable state, different from the original.

## 5.5 Visualization of food web response

***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.

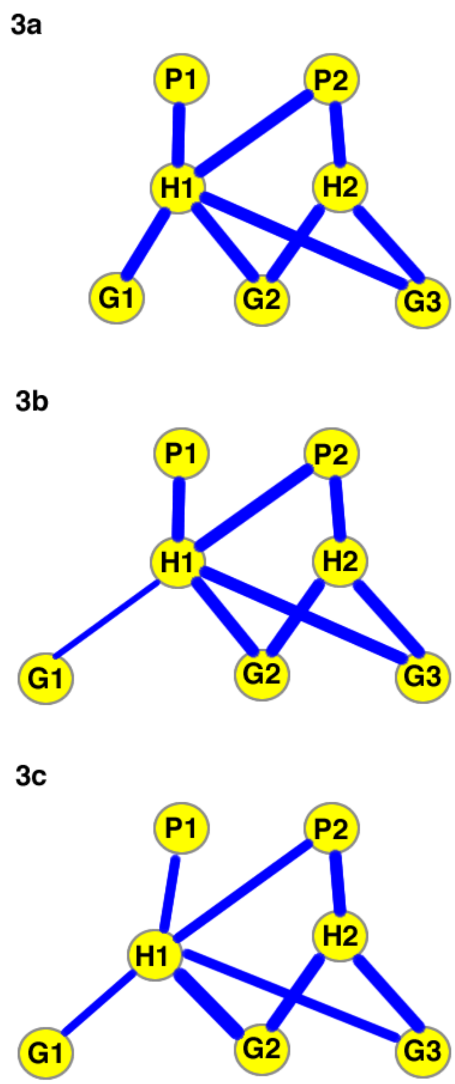



Figure 5-3. A network that starts in a stable state in which all the links have equal tension (a) until one node is disturbed and the link is stretched (b), followed by compensation by the entire network (c). During the period of compensation, some links are stretched a

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

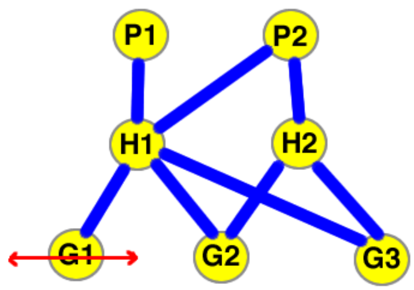
If the perturbed node is also allowed to respond, the entire network should return to the same geometry as it started with. If the perturbed node is held in a position for a period of time, the rest of the network may readjust itself to the same geometry but shifted over a bit.

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.

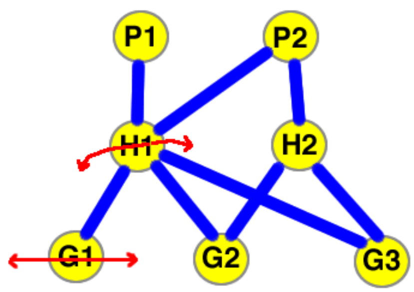
### Response to variations

In the previous diagrams, the position of the node in XY space represented both the environmental condition that the species was dealing adapting to. 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.

4a




4b




4c

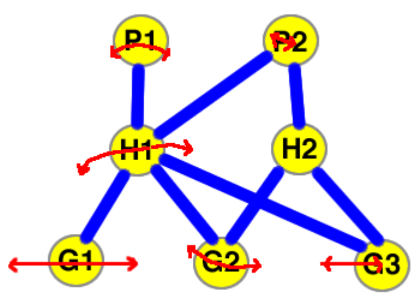


Figure 5-4. Propagation of an oscillation from G1 to other nodes in the network. Each subsequent diagram shows how the oscillation from the previous diagram might propagate next. As the nodes are further away from G1, the response can be considerably attenuated.

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.

## 5.6 Intermediate levels of connectivity are key

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 compensate for perturbations or variations. 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).

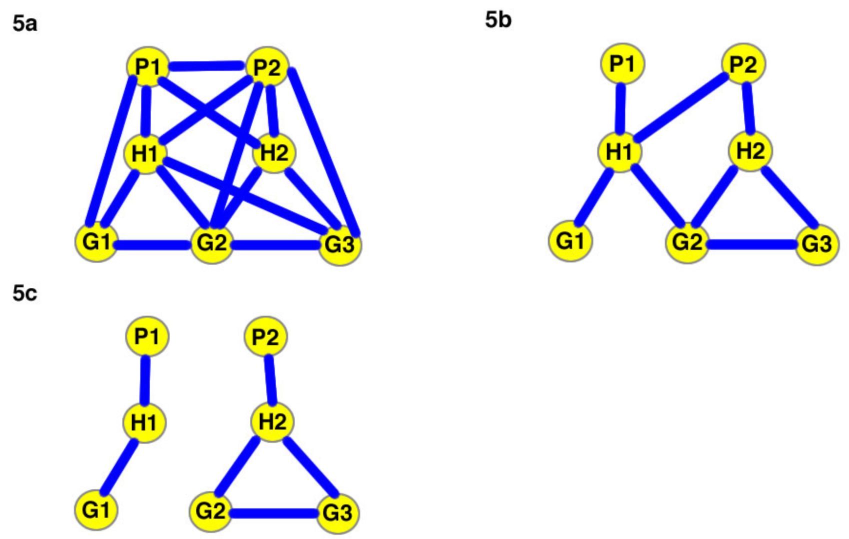



Figure 5-5. Range of connectivity. A is over-connected or crystalline, B is intermediate and C is under-connected or fragmented.

## 5.7 What makes a food web resilient?

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 healthy 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.

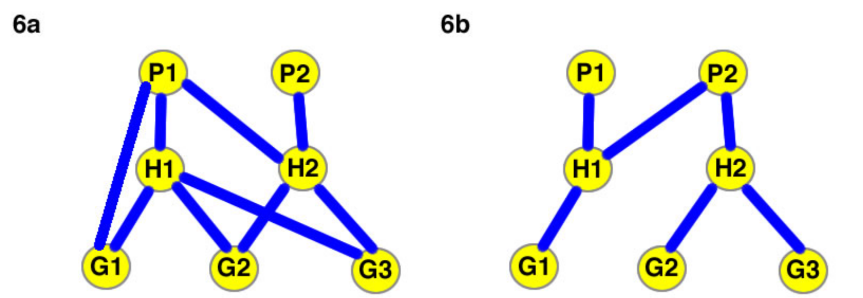



Figure 5-6. Two related networks that can shift back and forth depending on the health of the top predators. a) Predator P1 is very robust, is able to eat both

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.

## 5.8 List of the characteristics 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. Resilient food webs will have an intermediate level of connectedness, not too connected and not too independent.

4. A single perturbation will cause an immediate reaction and then several levels of response from the full network, depending on the connectedness. This allows the entire network to share in compensation for that individual change.

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 have a high threshold of resilience.

## 5.9 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 can cause 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?

### *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 (N,E,S and W but not diagonally). 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.

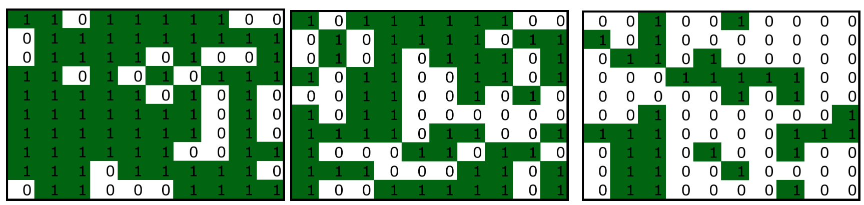


Figure 5-7. An ecosystem region that is divided up into patches. Each patch is connected to its four nearest neighbors. Different levels of random patch destruction are illustrated, a- minimal (30% loss), b-critical (41% loss), c-overcritical (60% loss). This figure was adapted from Sole and Goodwin 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

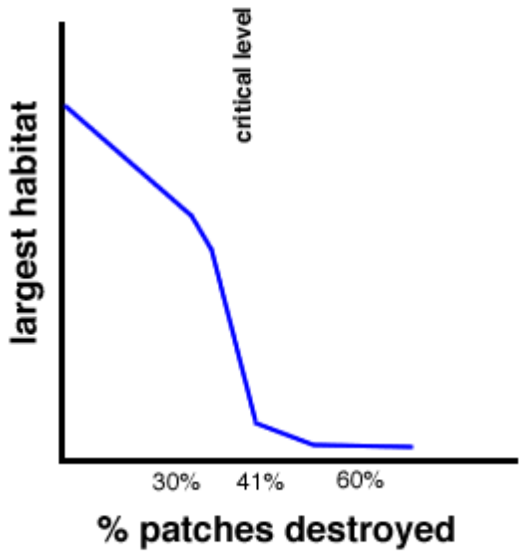



Figure 5-8. A graph of maximum habitat size against the proportion of patches that have been destroyed. Notice the critical level that is associated with a rapid loss of habitat size.

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 you 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 a potentially 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 be to little 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.

### *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.

### *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.

## 5.10 How you can use the network view

## 5.11 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.


# Chapter 6 – Stock and Flow Systems

## 6.1 Introduction

Ecological, geochemical and human processes can be described by following the flows of material or energy from one place or form to another. 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.

This text presents one specific definition of how to characterize an environmental problem as a system of stocks and flows. We will be using a limited list of characteristics of a system that can be used to describe many different structures and behaviors. Our constrained set of categories will help highlight the structural similarities and differences between different systems.

This "systems" approach is useful for simplifying problems, looking for significant processes and identifying controls. The approach can also be used to create simulations of future conditions and to communicate these to other people who are making decisions. Another 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. Thus, carefully gathering information to construct a stock and flow description of an environmental problem is a good example of methodically collecting information that takes place in scientific research (Pielke 2007).

## Comparison to network view

We can use 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. Even a study limited to just the dominant energy flows might be extremely useful. 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.

## 6.2 Model Components

There are five components that we will use to represent the structure and behavior of our chosen system: stocks, flows, information flows, convertors/constants and a source/sink. An icon represents each component. For example, look at the growth of a population of rabbits (see Figure 1).

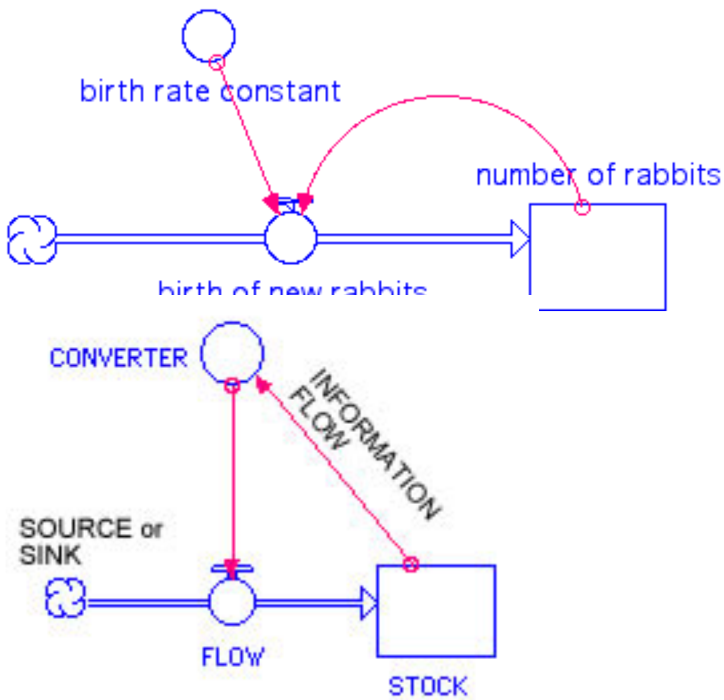



Figure 6-1. A simple systems diagram for the increase in a population of rabbits illustrates the five objects that we will use.

**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 a reservoir that is outside the boundaries 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 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 combined in flexible ways to describe the structure of different systems. An important value of this approach is that the structure of the model indicates particular types of behavior and the iconography helps visualize these structures. 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 pattern of growth shown in Figure 6-2 as population vs. time. (Of course the population can't continue to grow like this forever.)

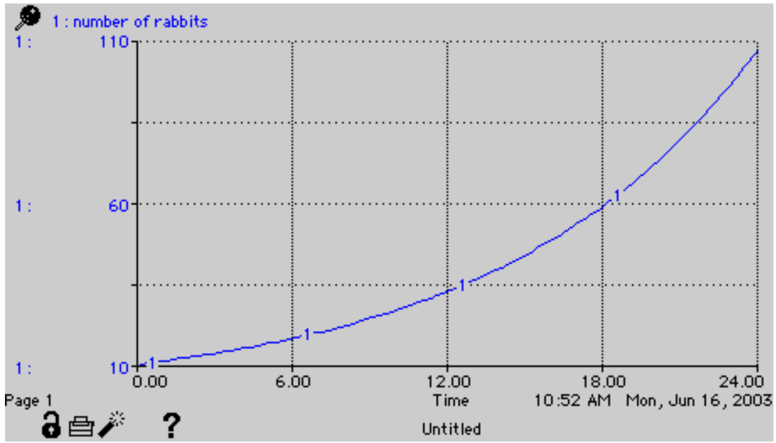



Figure 6-2. Rabbit population growth predicted from the model in Figure 1. The initial rabbit stock was set to 10 and the growth rate constant was set to 0.1 per month.

The structure and relationships in this particular model demonstrates “positive-feedback”. 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.

## 6.3 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 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 the 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.

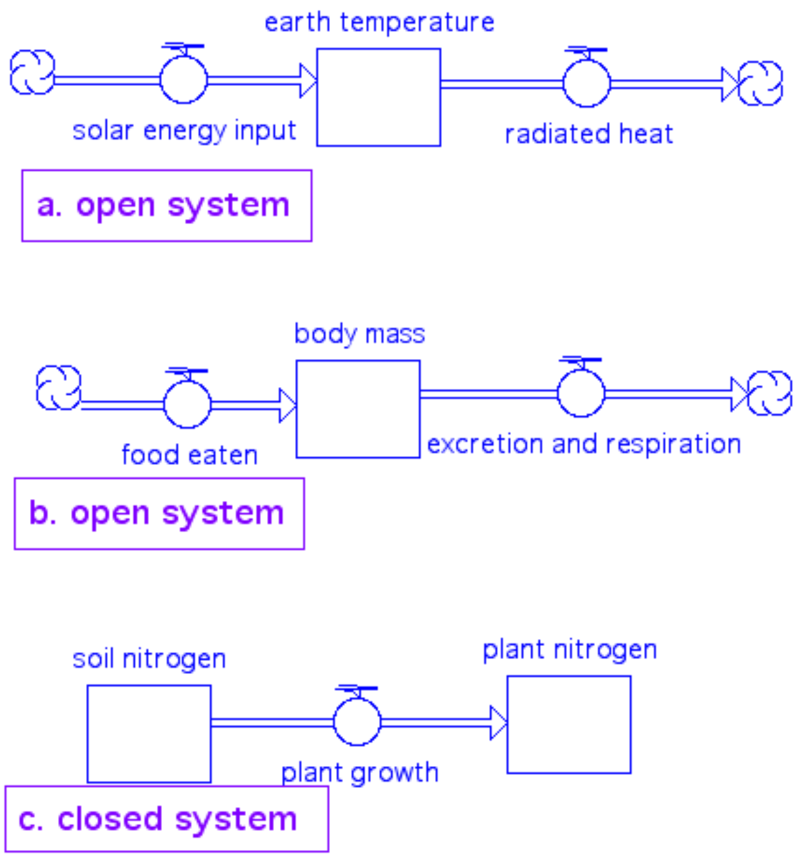



Figure 6-3: Several examples of open and closed systems. a and b are open, c is closed.

**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.

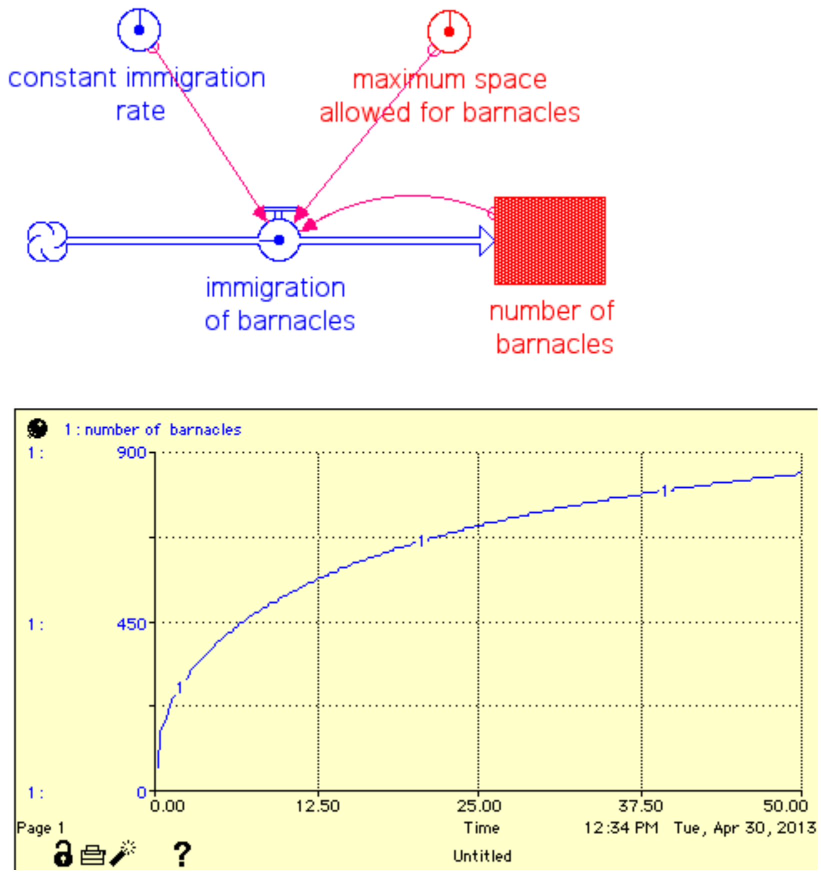
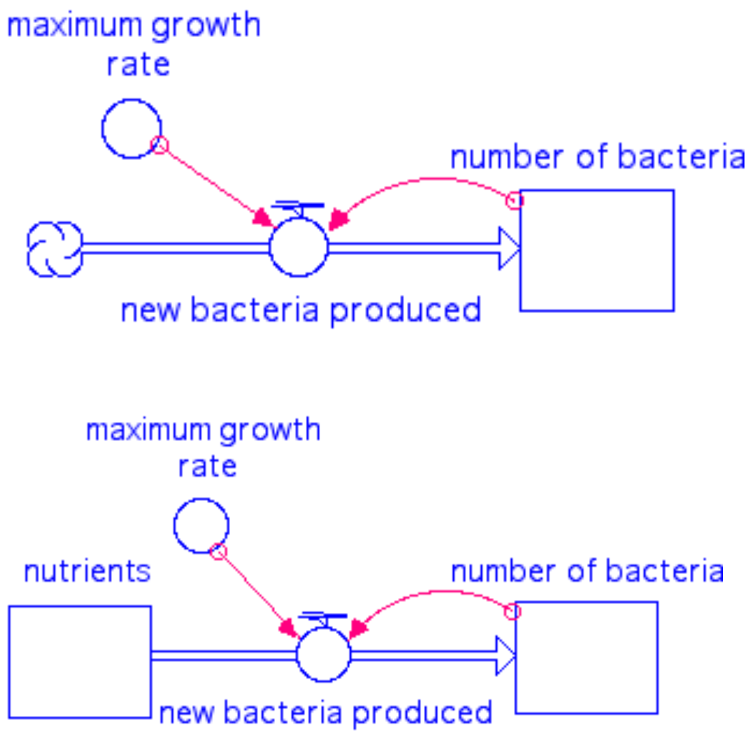



Figure 6-4. A system that contains a negative feedback control (shown in red, or slightly gray). The system wouldn't work without the other components. The number of barnacles continues to increase until it hits a maximum and then it levels off due to lack of any more space.

**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 one without stock limitation.



a.
b.

Figure 6-5. 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 $CO_2$ 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 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 tools of the network view.

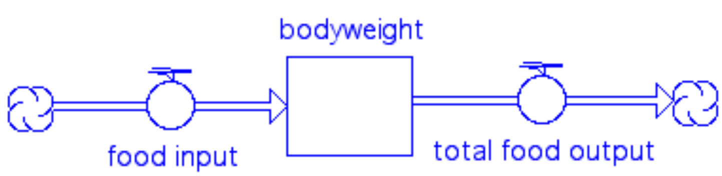



Figure 6-6. An example of a familiar steady state problem. If the input equals the output for a stock, the stock will remain constant with time, no matter how fast the input and output are. If the input exceeds the output, then the stock will increase. In this case food input is in terms of the weight of all food eaten and the food output is the weight of all excretion of waste, including the $CO_2$ exhaled. The variable part of the bodyweight is “food storage” that is probably fat.

## 6.4 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. There are other simple models that might contain two parallel paths to represent different forms of materials or energy. 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 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. A “busy” model contains several “simple” models joined together. 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 current population plus additions from births or immigration and minus losses from death or emigration determines the new population level. 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.

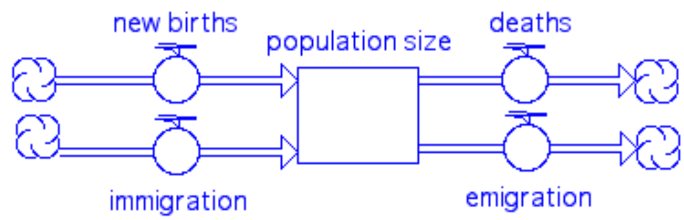



Figure 6-7. Population change. The population increases from birth or immigration and decreases due to emigration or death.

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.

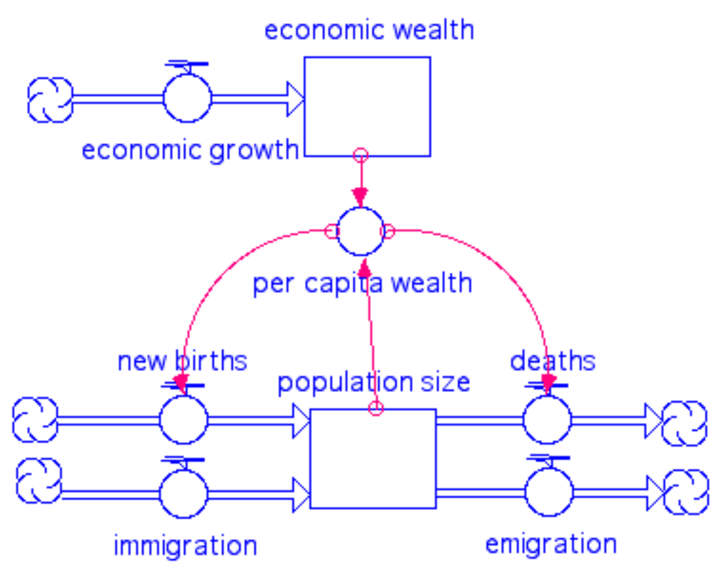



Figure 6-8. Busier model of population change. Economic growth in a country (which can be the result of industrialization) creates wealth. The economic wealth per capita is the total economic wealth divided by the population at any

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. Note that the structure of this model makes it clear that we are assuming that increased per capita wealth will have some impact on the birth and death rate.

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 is 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 is 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.

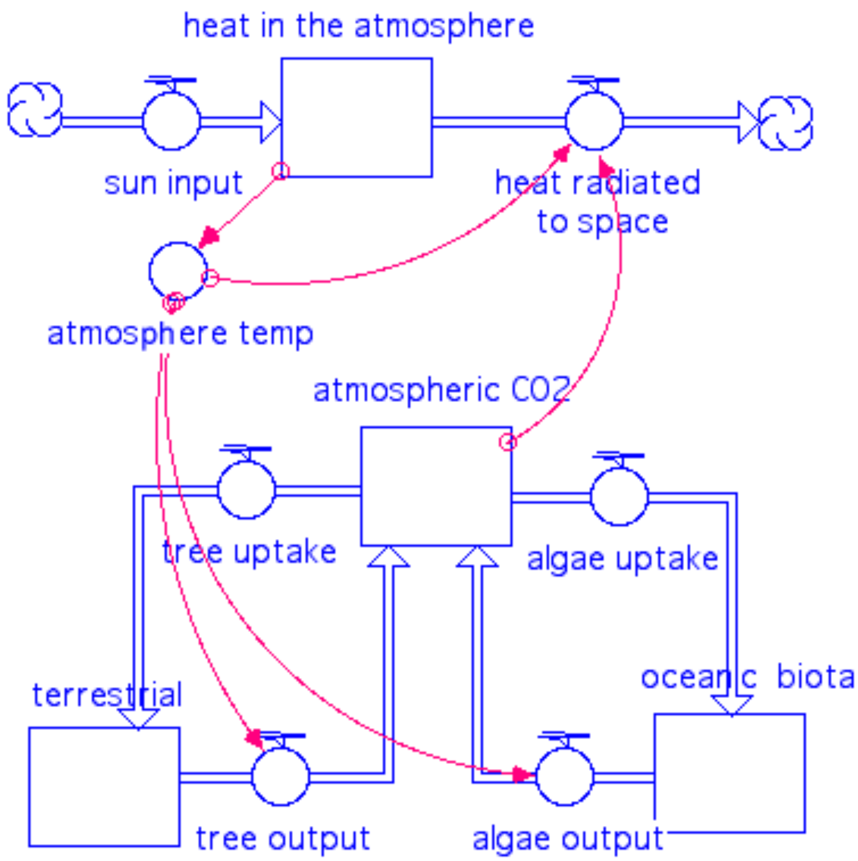



Figure 6-9. A busy model of atmospheric temperature and the geochemical cycle for carbon. The analysis, below, identifies the simple model parts and the linkages between these sub-models.

Analysis: This model is missing many important stocks and flows. Even with this deficit, 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 CO2 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. 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 for that outcome is as follows:

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 illustrate 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.

## 6.5 Starting Steps

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).

## 6.6 Overlaps and conflicts with other tools

| **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. |

## 6.7 Extending analysis 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 appendicies for this book to see simulations that were written in STELLA and simulations made available on the web (through Forio.com). In these simulations only the parameter values can be changed, not the structure of the model itself. But these simulations 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, the Northwest Power Council created a complicated and very busy model that contained information on fish, dams, river flows and electricity. This model could be run under different conditions and demands for energy to show which parameters affect fish survival most. They were able to show the model 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 were powerful tools in addressing problems and getting people to learn about complicated social, economic and ecological issues.

## 6.8 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. It maybe that you can have some resources decrease and be replaced by other resources. There are different definitions of overall sustainability that address whether the entire ensemble of capital types has to be stable or whether substitutions can be made.

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.

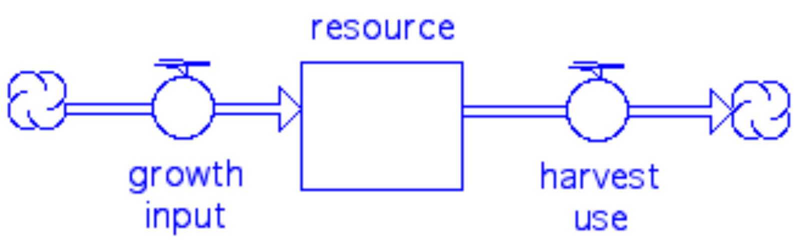



Figure 6-10. The starting assumptions for a model of sustainable natural resources are that input comes from growth and output goes to harvest. There are no other inputs or fates being considered.

If this resource is based in natural (biological) capital the growth rate will often depend on the amount of the stock. For example healthy fish populations grow faster with more fish and 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.

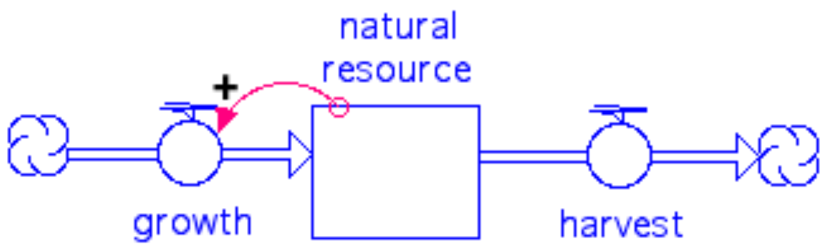



Figure 6-11. In a simple sustainable harvest model, the natural resource has a positive feedback on the growth of that resource. This holds within the region of healthy, and not over-abundant resource.

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.

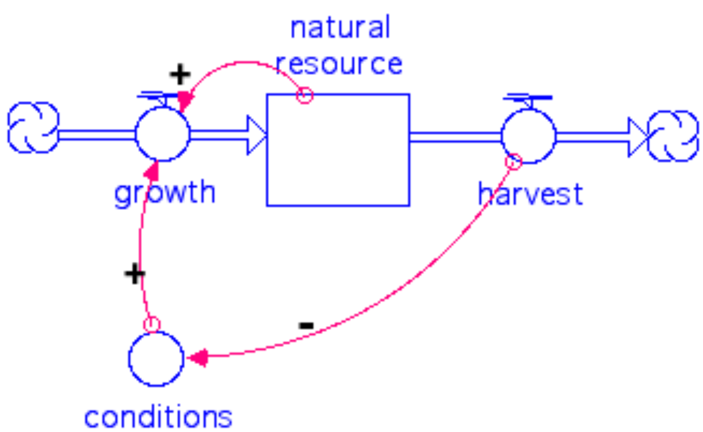


Figure 6-12. The mechanisms of harvest can have a negative effect on the conditions for growth. Overharvest can damage the microenvironment necessary for optimal growth.

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).

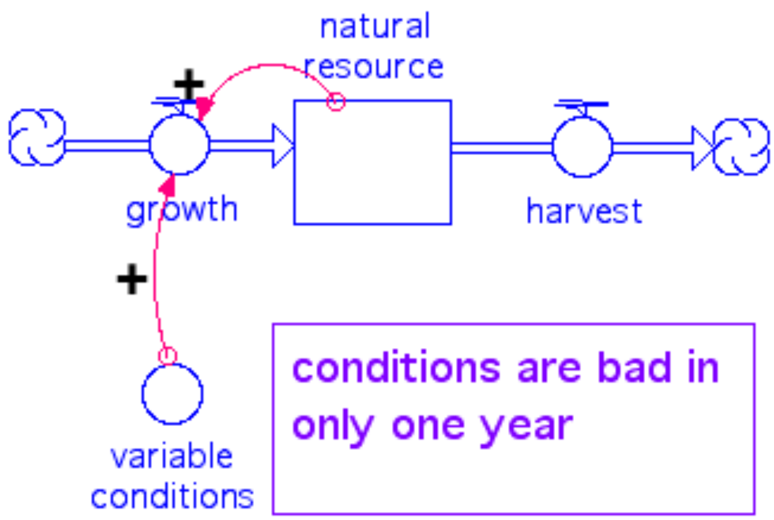



Figure 6-13. Conditions might also vary with time, such as a year of drought or unhealthy water.

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.

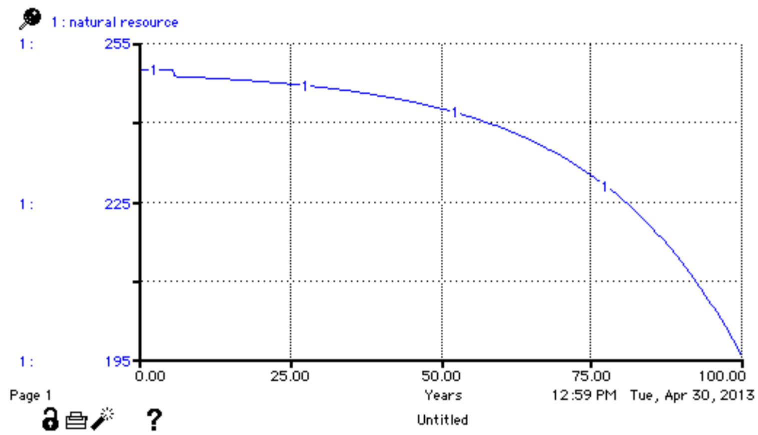



Figure 6-14. With just one bad year, holding to the previous "maximum sustainable yield" will eventually cause the collapse of this resource.

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 methods or use

c. risk of being too close to the maximum yield, one bad year and the resource declines dramatically

## 6.9 Summary

Methodically constructing a stock and flow model to represent the processes related to an environmental problem supports good practice for scientific information gathering. The constraints on the quantities that are being measured and followed forces the clarification of assumptions. The structure of the model can be visualized with iconography that illuminates the relationship to particular functions of the overall system such as feedbacks, stock limitation and possible steady state conditions. The basic assumptions for using a natural resource sustainably can be explored using this approach. The goal of sustainable use would be to have the input match the output and maintain a steady state for the resource. Positive feedback works to replenish the stock, but this is a double-edged sword, just one bad year can lead to an eventual collapse unless the harvest is decreased.

Analysis of these models involves taking apart each stock and flow and explaining how that part contributes to the overall behavior of the system. This is a very useful exercise for construction of the model and for communication about the important features of a problem.

As models become busier they often require sub-models for different stocks. The example of Easter Island demonstrated hypothetical relationships between the stocks of palm trees, people and rats. At high human populations, this system was not resilient to changes and might explain the decline of the resource base.


# Chapter 7: Environmental Accounting and Indexes

## 7.1 Introduction

Many discussions about environmental issues emphasize 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 the statement 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 still open for debate and, in fact, has been a very interesting debate in history, sociology, political science, economics and religion which we won't be able to resolve here. The second assumption (implication really) is that there is available information on the "true" or "full" costs and that we are ignoring or simply failing to use. This chapter will demonstrate the value of attempting to account for more than the immediate financial costs of human activities. It will also demonstrate how to distinguish pertinent information from nonessential information **AND** how to implement systems that can help us to make informed decisions based on this information.

Environmental accounting is very useful when faced with what was referred to earlier as “simple” or “information” problems (see Chapter 2). In these types of problems either we have all the information we need to reach a solution or it requires obtaining particular information through additional research (“information problem”). In the case of a simple problem, environmental accounting is a crucial part of monitoring and evaluating the progress of the chosen approach. We must verify that the actions accomplished the intended goal, that the solution was cost effective and did not exceed our budget, and that the long-range outcome was beneficial. For example, if we were planting trees along a stream, we might be very interested in improvements in the turbidity of the stream, shade cover during the summer heat, success of the trees planted, and time and money spent. We would also need to be able to collect this information at a fraction of the cost of the total project. Even though it seems as if those parameters would be easy to collect, they take someone's time and money to do properly. The results of many small restoration projects are never tracked because the cost of subsequent monitoring was either not planned for or considered to be too expensive. In the case of "information problems" it is important to determine both what information needs to be collected and what will be required in order to record and collect that information. As the information load increases, so does the time and effort it takes to examine, analyze and evaluate the data to make a purposeful decision. Some information problems are as simple as needing to assess the potential impacts of several choices. For example we might want to compare putting in several bio-swales vs. one large wetland at the end of the pipe. The best answer would depend on many local factors that need to be studied. Other information problems might require a much more sophisticated set of strategies to map out what research has to be done and what information will need to be collected from initial attempts, pilot projects or even stage one of a large project.

Environmental accounting procedures are an active area of research. People are trying to find out how to effectively extend the power of environmental accounting to problems that include conflicting social and economic values and to contexts that might contain surprises. The crucial issues for dealing with multiple values, such as individuals vs. society or different valuations between individuals, is that environmental accounting has no objective mechanism to handle these value conflicts. Several approaches are being tried and they are discussed below. Surprises, or unintended consequences, are also a major challenge for accounting systems because these systems are designed to provide particular types of information and a surprise, by definition, is the result of an unintended outcome has a fundamentally different quality than was expected. One response to this challenge is to use accounting to create indicators that can be used along with scenarios to make data-driven decisions in spite of substantial uncertainty.

There are several key aspects that accounting usually focuses on and a range of levels of aggregating the data. Several key terms are listed in table 10.1 that describe how much something is worth (in dollars), how much is owed and the revenue.

Table 7.1 Accounting definitions

| **Term** | **Definition** |
|---|---|
| Asset | Potentially tradable |
| Liability | Costs that are owed |
| Equity | Total wealth (= assets – liabilities) |
| Income or revenue | Money brought in |
| Expenditures or cost | Money paid out |
| Discount rate | Interest rate, such as 5% per year |
| Present net value | Back calculated dollar value from an amount in the future, using the discount rate. |

When data is collected, the values are assigned to show up in a system of accounts. This system of accounts will contain categories for like information that are meaningful and can be shared with decision makers. A major goal for accounting is to set up an array of accounts that captures all the information necessary, without double-counting and without duplication. For example, if one wanted to track the success of a riparian restoration project one might keep track of costs on plants, site preparation, planting, and monitoring. Even though data would be collected during site preparation and planting one wouldn't want to double count that as monitoring. It is also important to decide whether surveying and initial information gathering gets counted as monitoring or as site preparation. Also, it is necessary to determine what information is required to make subsequent decisions. If one were collecting information to inform the volunteers where and what to plant, one would need spatially explicit data for soil and micro-climate that would be favorable to the different types of plants. If, however, the overall goal of the project's sponsors was to prevent soil erosion, then one should provide measurements on soil loss and stream turbidity and not spend money and effort describing location and biodiversity. The accounting system must be tailored to the decisions that will need to be made, not collecting everything possible and sorting it out later. Accounting systems deal with different levels of information needs by collecting information at the base level and aggregating this, through analysis and evaluation, into metrics, indicators and indices. These will be discussed in a following section.

## 7.2 Several examples

Before continuing, let's examine several simple examples of how environmental accounting can help solve problems. More detailed problems are presented later.

***Bioswale Effectiveness***: Probably the easiest example to understand is performing an accounting procedure to verify that we are getting what we paid for on a project. Imagine that we are planning to use a bioswale to clean up the water coming off of a parking lot. In this case, environmental accounting is to a stock-and-flow systems approach (Chapter 5). We would measure the pollutants coming right off the parking lot and then measure the flow of pollutants into the stream at the end of the bio-swale. After correcting for the volume of flow and looking for potential losses or compounding factors, we would be able to claim that the pollutants of interest (such as heavy metals or oil) were less at the end of the bioswale than at the edge of the parking lot. We don't know where they went, but we know the bioswale did its job.

***Urban Tree Health***: A more complicated example might be to set up an accounting system for city employees who work with the urban trees to determine if the trees are getting healthier or sicker. Instead of lumping all of the work activities into a single account, such as time spent trimming trees, we could divide the description of tree trimming into categories that the employees could estimate. We might have three categories: trimming of healthy trees, removal of sick trees, and protective maintenance of trees. These categories may also make sense because these activities require different tools and supplies. For instance, if the public works department budget shows an increase in removing sick trees it is an indication that something might be going wrong. The challenge is not to over-burden the employees with information that will never be used but to collect enough information that will be useful to decision makers and analysts. Finding the balance requires knowledge and experience.

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. These include determining human preferences and tradeoffs, values of resources, and studying which processes and activities can be monetorized. In contrast to economics, 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 deciding what to measure, how to track and make decisions based on those measurements, how to provide support for businesses in charge of measurements, and how to tailor the approach so that it applies to many enterprises, from not-for-profits to profit-driven businesses. Thus the focus of accounting is to set up systems to collect objective data that can be used for decision-making and the focus of economics is to understand how humans allocate resources.

It has probably become clear that environmental accounting is similar to other approaches in this book. For example, there are many similarities between an accounting approach and a stock-and-flow system (Chapter 5). Understanding the four types of problems (described in Chapter 1) helps characterize which problems are amenable to a straightforward accounting approach. Some accounting problems, though, build on a rigorous biophysical systems model that must be constructed first. A good example of that will be setting national accounts for water quality and amount (described below). Traditional environmental accounting has difficulty dealing with uncertainty and unintended consequences, but there are new variations that are addressing this. An example of how to use accounting to create indicators that can be used in scenario analysis is provided below. Scientific adaptive management (Chapter 18) requires rigorous monitoring and assessment protocols that derive from environmental accounting procedures. Attempts at accounting for environmental and social impacts often are a crucial heuristic device to illuminate gaps or failures in the current system. Environmental entrepreneurs (Chapter 19) employ innovations in technology and institutions to fill these gaps in service or function. The problems that aren't easily addressed are those that include the range of individual and social values (described in Chapter 11). Thus, even though environmental accounting doesn't "solve" problems that contain high levels of uncertainty or human values, the process helps to frame and track problems.

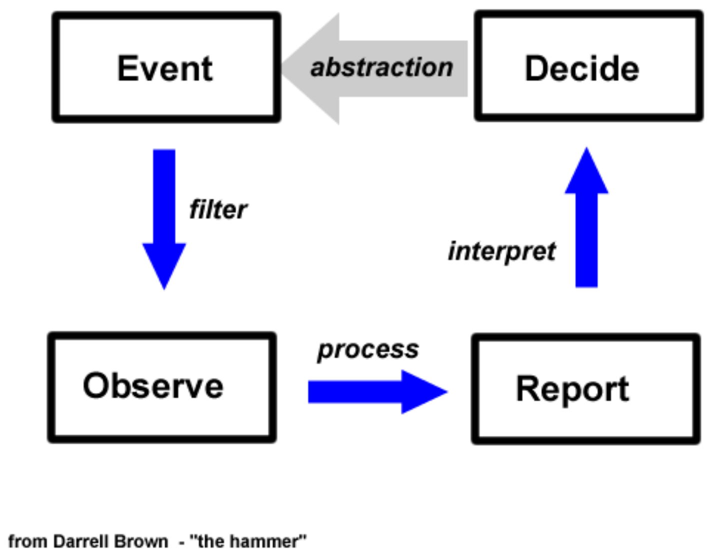
The two biggest challenges, alluded to above, for environmental accounting are to deal with human values in an objective and systematic manner and to construct systems with the right level of complexity. Attempts to incorporate values and objective facts always run up against philosophical and ethical roadblocks. There is continual debate among philosophers about the “is/ought” problem and the conclusion is that one can’t get from facts to values. This means that on a philosophical basis, one can’t set up a purely objective accounting process that will lead to making value decisions. Judgments will always have to be made by people in a separate process, such as a market or election. Accounting systems can aid these decisions by providing and certifying that the information has a degree of completeness and validity. Similarly, the issue of who should make decisions is dealt with by environmental ethics. The argument ranges from one extreme, in which it is believed that scientists should remain at arms-length from decision-making (and only provide information), to another extreme, in which it is believed that scientists and other people with close personal experience with the system being controlled should actively participate in the decision because they have the best understanding (Norton 2005). Acknowledging that environmental accounting faces philosophical and ethical issues will help us use this approach more judiciously.

## 7.3 Setting up an accounting system to support a decision

The purpose of environmental accounting is to create a system to generate information that can be used in the decision process. The prerequisites for setting up accounts include defining the question to be answered or decision to be made, identifying who will make this decision and characterizing as specifically as possible the information that will be needed. The characterization of the information should identify which non-overlapping categories will be established and the sources for each type of information.

The actual process of 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 and places information in one of the pre-established categories
- 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




This accounting method is very similar to how we have described the scientific method. The role of accounting is to decide the criteria for applying filters, which is similar to the discussion about whether science only looks at objective data and leaves value decisions to managers or whether, in post-normal science, 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. Similar to traditional science, traditional accounting has strengths but the underlying method may have to be adapted to address values and facts.

One of the goals in accounting is "completeness", which is the accounting for everything that is relevant without double counting. This is important because if the quantity being counted is being paid for, the purchaser needs to know that that quantity hasn't been paid for already. A good example of this challenge is the tracking of forested land that is being set aside for conservation. The benefits of setting this aside are preserving biodiversity and carbon sequestration, i.e. keeping the carbon fixed in the trees and soil rather than allowing the forests to be cut. This latter approach, called Reduction of Emissions from Deforestation and Destruction (REDD) attempts to account for all the carbon tied up in the trees that would have been released. It is difficult enough to measure and estimate the amount of carbon in trees and soils. But there is another challenge. What if an agency or NGO makes a deal with a company not to log a particular plot of land? The carbon is fixed in that particular parcel. But what if the logging company then deforests an adjoining or even remote plot instead? The intent of the accounting process was to decrease carbon emissions, but for obvious reasons it failed. This situation occurred in Bolivia (ref), where there was a very aggressive plan for REDD. The sticky point was that the logging operations, which have limited capacity, could simply go across the border and cut trees elsewhere. Such challenges are not easy to resolve.

There are many different "flavors" of environmental accounting. Each of the variations has particular benefits and weaknesses. Several of these are listed below.

Triple Bottom Line – Uses multiple types of accounting assets that don't all have to be harmonized to monetary quantities. Usually the three accounts are economic, social and natural capital. This approach makes the progress in social and natural capital apparent, but strategic decisions still depend on the judgment of the relative value of the three accounts.

Ecological Footprint – Collapses all activities onto one dimension of its carbon production or reduction. This carbon budget is then expressed as the amount of average arable land it would take to offset this carbon production. This provides for a very dramatic and easily understood description of human impact. It is difficult to expand this footprint to account for social or other ecological functions. A simple carbon budget might be preferable for accounting purposes so that water and other environmental impacts could be accounted for separately.

Water footprint or embedded water – The total amount of water used in products and services is calculated from the beginning on through to consumption and disposal, i.e. the life-cycle of the product or service. This approach is very good at emphasizing the collateral water use such as how much water it takes to put a pound of beef on the dinner table or the amount of water used to create and then wash or dispose of different types of diapers. The focus on water is useful given that this resource is becoming scarce around the world. However, like the carbon footprint or other single-attribute accounting systems, it is difficult to combine this with other metrics because of double counting. For example, water, energy and land are all involved in the production and disposal of diapers. It is not appropriate to merely sum the impacts since they overlap.

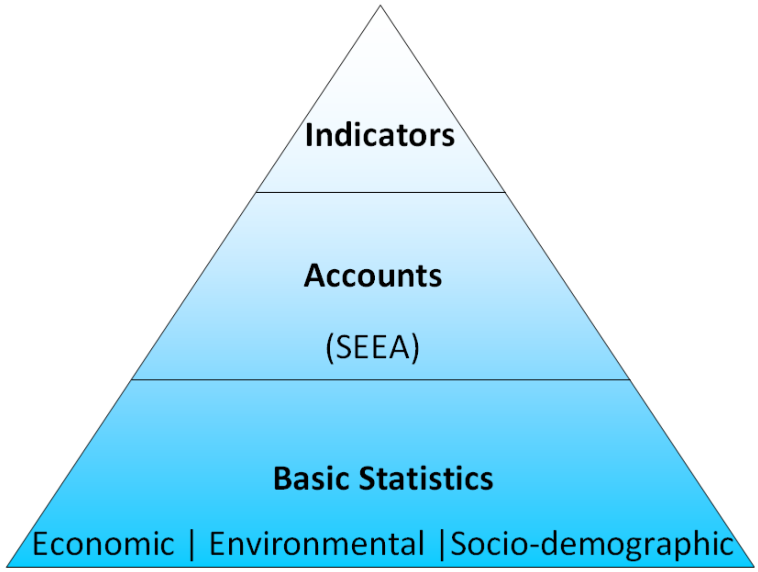
Ecosystem Services and Natural Capital – The accounting aspect of these economic concepts is to monetorize the values of ecosystem services (such as clean water production) or the capital value of the natural resources (such as a healthy forest). A major benefit of this approach has been to show that investments in green infrastructure, such as marshes or forests, are a reasonable economic alternative to hard infrastructure such as sewage treatment plants or dams for flood control. There is resistance to the over-use of these approaches because they fail to account for the non-monetary aspects of nature and thus seem to be making a pre-judgement that those values cannot be used as a basis for decisions.

Total community development – This approach accounts for improvements in human conditions and their surroundings in terms of the capabilities of the people. This accounting system is the partner to a different type of economics espoused by Senn and Nussbaum that focuses on how people develop capabilities to lead a meaningful life and the value of the freedoms that enable this development. Although the focus is primarily socio-economic, for much of the world's poorer people, environmental conditions are a major determinant in their well-being.

## 7.4 Accounts-metrics-indicators

Environmental information can be described as having three layers. The first three of these (basic statistics, accounts and metrics/indicators) form the information. The indicators can be aggregate multiple indices together to create indexes. Indexes will be described in the next section.

Figure 7-2 The "information pyramid" (pulled from references-notes****).




Data and basic statistics are collected through monitoring and research. There are many forms of data that derive from work in economic, environmental and social research. The overwhelming magnitude of the data makes data management strategies crucial (storage and retrieval) but also makes it difficult for casual users to access in a meaningful way. For example, for Upper Klamath Lake in Oregon there are over a million data points available on-line to anyone but these represent different locations, times and methods. It takes a sophisticated data analysis approach to sort through this much information to find answers to a particular question.

Accounts are essentially bins into which the data can be pre-sorted. These accounts should be set up before collection and have agreed upon methodologies. There are two goals for setting up accounts: identify a strategy that will collect enough information so as not to miss any important process (completeness), and use the accounts as a method to avoid double counting of some aspect of the problem (non-duplication). It is a skill to set up these accounts because it involves an understanding of what data is available melded with the very practical understanding of how the information will be used to make decisions.

The apex of the pyramid is the construction of simple metrics or indicators. These are derived from the information collected but are crafted to convey a message about the system that is clear and easily understood on its own. These indicators can be derived from qualitative data (*** more here). Some indicators follow the response system and are called “lagging indicators”, while others may predict an important change and are called “leading indicators”. According to Jakobsen (****) the key characteristics of indicators are:

- relevant, pertain to something you need to know
- stakeholders can understand them easily, they are intuitive for public
- reliable and give the same message in different situations
- based on accessible data that can be obtained in time to act

There are three types of indicators for the state of the environment, sustainability.Charts and maps are often very good tools to present an indicator. Take, for example, a map that shows the flood stage along a river. This easily conveys both the danger from floods at those locations above flood stage, but also is a leading indicator for what will happen downstream. Other simple yet powerful indicators are the number of people who are currently seeking employment or the number of permits to build new houses that are issued on any given day. Some environmental indicators combine several factors into a scale. The threat of forest fires is based on how dry the forest is (cumulative effect of recent precipitation), the current temperature, and the projected weather forecast. This is presented with simple “speedometer” signage along forested highways with the intent to get people to be even more careful when the meter says “high” or “extreme” fire danger. Such indicators might seem obvious if you are familiar with that area, but can be very useful in getting the attention of someone driving through the region

## 7.5 Indexes

Indexes are the compilation of data from indicators and basic metrics. Many of these contain a large number of data sources and are weighted. Most indexes contain so many pieces of data and are calculated with such complicated formulae that the workings aren't intuitive to the general public. Indexes are very useful for tracking longer trends or larger scale processes, but, because they have high information and analysis demands, they aren't useful for short-term management.

There are several common indexes that we see all the time, such as the Dow Jones Average, GDP, and Consumer Price Index. These are widely used to make financial decisions and actually have a big impact on how we think about our human activities. Using the wrong or biased set of information to make decisions can steer society in the wrong direction. There is significant discussion about using strictly economic indexes or adopting some indexes that include social and environmental attributes. A recent book by Vice President Al Gore (2013) critiques the gross domestic product index and states that GDP "is based on absurd calculations that completely exclude any consideration of the distribution of income, the relentless depletion of essential resources, and the reckless spewing of quantities of harmful waste into the atmosphere, oceans, rivers, soil and biosphere." You don't need an index to tell what Gore thinks of using the GDP. In a more measured volume, Stilgitz, Sen and Fitoussi (2010) argue that GDP is a mis-measure of our real economic performance because it ignores a wide range of services and impacts of the economy. They recommend shifting the "emphasis from measuring economic production to measuring people's well being".

Fortunately, there are a many indexes being developed and tested that address human and ecological well-being. It is not sufficient that a good set of data and indicators be compiled into an index; the index has to be tested for reliability and decision makers need to make a commitment to assess their progress based on these indexes. For example, it might be interesting if a state were to declare that it was making decisions based on the Genuine Happiness Index (see the table below), but if the actual effectiveness of the state government depends on taxes, then the state employment and economic indexes would be more useful. Of course it would be nice if everyone were happier, but if there is no support (financial) for taking such actions, then it is an empty exercise. Using indexes to make decisions requires paying attention to the entire accounting cycle of deciding what needs to be measured, setting up a system to get that information, and making a decision.

Table 7.3 Example indexes that measure environmental and social progress. This table was adapted from van der Kerk (****).

| Name | Short description | reference |
|---|---|---|
| SSI | 22 indicators in 5 categories and information easily compiled | |
| Human Development I | UNDP, good for developing countries | |
| Env Sustain Index | Requires a large amount of data | |
| Environmental Performance Index | 6 categories and 16 indicators, focuses on dimensions in the Milenium Development Goalls | |
| Genuine Progress Indicator | Similar to ISEW as a “green” GDP, can be used to track investments in different sectors | See Maryland |
| Ecological Footprint | Published by WWF, converts all consumption into units of land needed to meet that carbon | |

| | | |
|---|---|---|
| | demand | |
| Millenium Development Indicators | Established by the UN to measure development goals in developing countries, not sustainability | |
| Happy Planet Index | Life satisfaction x life expectancy/community ecological footprint, very intuitive index | |
| Gross National Happiness | Matrix of indicators, in use in Bhutan | |

## 7.6 Using indicators with scenarios

Scenarios are different forecasts for the future. Although general scenarios, such as those presented in the Millenium Ecosystem Assessment, are very useful for imagining the consequences of our actions and inactions, more defined scenarios can be useful for environmental planning. These scenarios have to apply to specific regions and time and have markers for progress.

Indicators have three purposes when used with scenarios. First, they need to be designed and matched to the problem in order to support expected decisions. This is the normal function for indicators in an accounting system. The second function of these indicators is to involve broader participation from stakeholders and the public by describing clear and interesting mileposts. This is not "greenwashing" marketing; instead, it attempts to identify the results that the community wants to see accomplished. Third, these indicators serve as the basis for quantitative simulation modeling that can illustrate the system behavior. For example, the Maryland Genuine Progress Indicator website has interactive simulation models available to the public that allows them to see the possible future outcomes from the investment in different projects right now. Scenarios with matched, measurable indicators become more and more important as the problems become more complex and public involvement is required for any true progress.

## 7.7 Examples of environmental accounting

****each of these will be expanded to text with a picture*

***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)

refer to similar case in BC where discount rate made the whole difference

***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 CO2
$2 to 16 per metric ton in the cost efficient areas
<!-- do they really mean ton of CO2 or ton of carbon?-->

Carbon accounting in a forest that might burn

## 7.7 Summary

Environmental accounting is the process of setting up information systems that are designed to monitor events and provide on-going decision-making support. There are many examples of environmental accounting informing major policy or economic decisions. The methods for accounting attempt to provide complete information without missing crucial information or double counting any pieces of data. Data and raw information is processed with statistics for reliability and trends. This processed information is usually sorted into different accounts to track specific aspects of the problem. Indicators are used to clearly represent the data to a broad audience. Many different sources of information may be combined into indexes. There are several familiar economic or financial indexes that are commonly used, but the environmental community is trying to replace or augment the use of those with indexes that track human or ecosystem well-being.


# Chapter 8 – Risk and Uncertainty

## 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 everyday work.

This chapter builds on previous chapters that help us describe the current state of the environment and 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 of irreducible uncertainty, cases where it is impossible to predict 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; however, the impact of the insecticide, how it may change the ecosystem, is 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.

Because we will deal with these in different ways, 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 future will actually happen.

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

> Sometimes our actions actually increase 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 is known 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.

### *Assessing our current level of understanding*

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 we are 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 overfish a region, it is reasonable to expect there to be fewer fish; however, we would be surprised to discover that overfishing has resulted in a sea filled with jellyfish. The ecosystem has flipped to an entirely different food web dynamics.

There is no absolute amount of risk or uncertainty that we find acceptable. In fact, 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, whereas others believe that progress is generally beneficial and requires tradeoffs 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*

Though many believe otherwise, 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 unlimited money, 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 for an emergency study 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? Similarly, 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 may be able to collect, enter and manipulate data with geographic information systems, there is still a unique set of characteristics and history for every location on the planet that must be considered. Second, because of the geographic 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 different places and/or individual involved increases the 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.

### *Cultural and worldview perspectives on risk*

The perception and response to environmental risks has a strong cultural context (Douglas & Wildavsky 1982). Some communities deal with risky environmental factors all the time and it changes how their point of view (Under the Volcano – Lowry 1947 ). 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 worldview groups deal with risk differently. For example, Douglas and Wildavsky (1982) list four main types of risk (Table 8.1) 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 may not be 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" |

We will discuss worldviews in more detail in Chapter 11. The important point in this chapter is that differential sensitivity to risk also means that there is no generally agreed upon definition of acceptable risk. For example, egalitarians would rate the risk of pollution much higher than the other worldviews. Continual dialog is needed 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 worldviews 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 solutions differently.

## 8.3 Using simulations to understand risks

Global change with a small chance of flipping to the other mode and then what would it cost

Show simulation of threshold --

## 8.4 A large portion of the uncertainty can't be turned into risk

There are portions of the overall uncertainty that could be expressed as a probabilistic risk if more research were carried out. This is un-quantified risk. But there are types of uncertainty that cannot be turned into risk. This requires us to deal with uncertainty differently than just recommending more research to reduce it to risk.

There are two major components to uncertainty, variability and limited knowledge. Table 9-2 presents a summary of these. Due to variability, some sources can translate uncertaintly into risk if more knowledge is gained, such as a better understanding of the range of values held by the population. Others are not amenable to any transformations that would allow a probabilistic statement to replace our uncertainty. In the category of "limited knowledge", we can reduce uncertainty by generating more exact measurements, collecting more data, and building new ways to measure processes that are cheaper. But the other sources of limited knowledge are pushing the boundaries of what we can ever learn.

Table 8-2. Uncertainty due to sources of variability and limited knowledge. Adapted from van Asselt and Rotmans (2002).

| ***sources of variability*** | |
|---|---|
| inherent randomness | non-linear or chaotic nature of the process |
| value diversity | differences in people's mental maps, worldviews and norm |

| | |
|---|---|
| human behavior | non-rational behavior, deviations from normal, or discrepancies between what they say and what they actually do |
| social | non-linear or chaotic nature of social systems linked to the process |
| technological surprises | breakthroughs or qualitatively different technologies |
| ***limited knowledge*** | |
| inexactness | lack of ability to measure or measurement error |
| lack of data | lacking data that could have been collected but wasn't |
| practical immeasurability | technically possible to measure but too expensive or other similar reason |
| conflicting evidence | directly contradictory datasets or interpretation |
| reducible ignorance | we don't know what we don't know |
| indeterminancy | we understand enough of the laws governing the processes to know that they lead to unpredictable outcomes |
| irreducible ignorance | we cannot know |

One approach to reducing uncertainty in highly complex situations is to allow or rely on technical experts to make decisions. This approach removes the uncertainty that comes from injecting a range of values into the decisions and the often non-rational behavior of humans. For example, technical experts should be able to sort out the quality of data and evaluate the merit of technical solutions much more objectively than the general populace. Establishing a technocracy in this manner changes the nature of the uncertainty from technical to social and governance. By eliminating values from the discussion and usurping the public's power and responsibility to make decisions, the uncertainty of democracy is replaced with the indeterminacy of imposing a technocracy, "an all-powerful enlightened Leviathin" (pg 2, Press 1994). Technocracy, especially the command-and-control centralized variety, presents a challenge to democracy. The tenets of democracy cannot be made if we empower someone else to make decisions that involve the allocation of resources in our society. Press (1994) explains that even within strong democracies such as the United States there are decisions that are shielded from simple democratic votes, such as how the Supreme Court is designed to be isolated from legislative and executive actions. Pielke (2007) proposes another template for incorporating strong technological expertise into decisions without it being a technocracy. He suggests that the scientific community must present a range of options to decision-makers and provide un-biased and objective information that is relevant to the decision process but should let the democratic processes reach decisions. The point is that trying to remove uncertainty by employing experts (who have access to large amounts of information and analytical skills) merely shifts the uncertainty from a mix of values and objective facts to, arguably, an equivalent level of uncertainty centered in the domain of governance.

Uncertainty has value, and we might want to learn to embrace those qualities rather than trying to reduce uncertainty at all costs. Berry (2008) suggests that we examine the assumption that more knowledge and less ignorance will help us avoid bad consequences. Vitek and Jackson (2008) suggest that a worldview based on control through rationality should be replaced with a more humble view that is "predicated on the assumption that human ignorance will always exceed and out-pace human knowledge" and we should essentially learn to lead with our strengths (ignorance). Surprises that come from uncertainty are key components of individual and institutional learning. Eliminating or managing uncertainty to the point of avoiding any surprises would dramatically decrease our learning (Gross 2012). Thus learning to deal with uncertainty has advantages that would be masked if the goal were to eliminate it or project the many dimensions of uncertainty onto a simple dimension of risk.

## 8.5 Summary

Much of this chapter has dealt with the challenges of dealing with uncertainty and risk. My warnings are 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.

# Chapter 9: Values and World Views

## 9.1 Introduction

We must employ our best intellectual efforts to effectively address environmental problems. This requires that we join the effort to bring together substantial information on these problems, analytical tools, and an understanding of how our individual and societal values interact and mold our actions. As I've demonstrated in this textbook, it is straightforward to address the required knowledge and useful analytical tools. However, it is more challenging to describe how our values, as individuals and as a society, can be integrated into scientific management. In "science" we purport to look for evidence that would prove our hypotheses and claims false, but the rest of the time we collect evidence and stories that fit in with our preferred schema for how the world works and confirms (not refutes) our biases. Understanding how worldviews and their underlying assumptions shape environmental arguments is a valuable tool in working with broad range of stakeholders that we confront in a pluralistic society. This chapter describes the importance of factoring these values in the definition of environmental problems and outlines the types of values that we can and can't deal with in a scientific manner.

## 9.2 Judgments and values are present in every problem

Scientific environmental management deals with problems. A problem is any situation that 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 in 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 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. The focus of this chapter is how four or five categories of worldviews can be used to describe the bulk of value-related discussions in environmental problems. These worldviews are each self-consistent sets of values and preferred analytical approaches that reinforce each other.

### *Why an explicit treatment of values is important*

Just because an approach seems to be more objective, doesn't mean that it is necessarily any less prone to errors. 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. Providing objective information at an arm's length doesn't eliminate judgment; instead, it pushes all of the judgment to the beginning of the process. One begins by deciding to use a particular method of data gathering and analysis and then agrees (sometimes before any information is available) 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. This chapter will also show that this process can be rigorous, unbiased and extremely useful when addressing complex or 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
    - o felt values - strongly held values that are unlikely to change (Norton)
    - o considered values - may be altered or negotiated
    - o fundamental preference diversity- range of strongly held beliefs, similar to felt values (Page)
    - o 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 consumpetion 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 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 the rights of individuals in a society to access 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.

## 9.3 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 one can examine a population and find a range of values and combinations of values; however, 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 deem natural capital preservation of lesser value because they think they can replace it with technology. However, this broad typology should not make one 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 also favor increased efficiency as a solution to problems over strict conservation (like the industrial or accommodating ecologist category).

Table 9-1 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 and market incentives | all capital is convertable, weak sustainability | equity for all<br>instrumental value in nature, utilitarianism |
| Communalist - committed environmentalist | preserve resources | strong sustainability | green economy<br>collective interests take precedence over individual human interests |

| | | | |
|---|---|---|---|
| Deep ecology | preservationist<br>severely limit resource take | very strong sustainability | broader definition of rights (animal, plant and earth system) |

The purpose of this table is illustrate 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 from how groups think society governs itself and what groups think the role of individuals should be 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
- people 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 worldviews 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 their general mythology of how the world operates supported. Although you may agree with the premises that lead to a particular worldview, it is crucial that you learn about the other viewpoints and are able to assess your understanding based on a wide range of information. The multiple-perspectives framework is a start toward achieving this goal.

Table 9-2 Comparison of two typologies of worldviews, MEA scenarios, cognitive biases and underlying metaphors or mythologies.

| Governance world view | Ecology sustainability world view | MEA scenario | cognitive biases | example metaphor or myth |
|---|---|---|---|---|
| Individualist | Cornucopian | Techno-Garden | | survival of the fittest |
| Hierachist | Industrial ecologist | Global Orchestration | quantitative systems tracking | |
| | Committed Environmentalist | | | |
| Egalitarian | | Adapting Mosaic | cooperative nature of networks | |
| | Deep Ecologist | | | |
| Fatalist | | Fortress World | | |

Another example of how worldviews differ in 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 stages and developing the spirtuality and knowledge to interact with other people. The fourth, fifth and sixth levels of development are of interest to us. Wilber (2000) also describes the approximate proportion of the US population that is in this stage and the relative amount of power that they have in society. This is interesting because the level/worldview that has the potential to impact the environment most dramatically, i.e. the individualist, has power that is out of proportion to the 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 use their values in a consistent manner to act on information about the environment. The 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", and one’s decisions have a high chance of being correct. When one’s view and the actual structure don't match, this is called a "dystopia". One 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 are thoroughfares. 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, worldviews may be driven by an ideology that is not easily changed. For example, dyed-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 here on individuals 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.

## 9.4 An overview method for including values

This chapter presents one possible method for bringing values into the discussion of 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 a 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 multitude 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 who use that as a platform to voice their unfounded, anti-pluralistic complaints. If they don't respect the worldviews of 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 from 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 into 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 where the fix is already built into 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 related to dealing with scale in environmental problems (See Chapter 3), and one of them is to decide how many people can actually participate in the conversation on a particular problem. The community may be all the people and groups that are involved in this specific problem and who can demonstrate that they are dependent on the results.

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 may be vague or ambiguous on particular topics. The important point is that everyone 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 and evidence 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. Pre-experiential or ideological approaches are not permitted to serve as evidence. Another point that he makes is that values are also up for discussion as well as 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 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 concrete descriptions that can be presented, discussed and modified. The key part of this stage in the process is that the discussion focus on only on the technology, knowledge and assumptions of these scenarios. The discussion must be limited to what the community has agreed on and is committed to solving. It is very easy to widen the problem by adding in other issues. If that happens, the community must agree to widening the scope and the composition of the community must be examined to see if it needs to be more inclusive as well. For example, it is not uncommon for communities to worry about whether the particular place-specific solution represents a variance or exception to policy that would serve as a dangerous precedent. To bring in this issue is to generalize from the solution proposed to a wider scale. But before policy implications are considered, the community must agree to include these implications in the problem statement.

### ***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 hidden in the jargon of a particular discipline or profession
- maintaining mutual respect
  - eliminating input from people who are not committed
  - eliminating input from people who have espoused values that don't match their real values
  - silencing 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 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, which prizes efficiency and effectiveness over 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 to or responsibility for the solution, the solutions will probably follow governmental policy closely. An example could be the restoration of a stream located in a state park. The park officials would probably play a controlling role in both the problem statement and identification of 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.

## 9.5 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. A major reason for this is that while it is inefficient to learn facts about the environment through experience, experience is necessary when defining 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 from the task of studying authentic problems and experience making value judgments (Schwartz ****). Obviously, most educational activities will have to be 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.

There are four parts that contribute to this language/experience gap:

1. We need to extend our common language to be able to describe key values.
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 problem-solving and judgment-developing experiences for students studying the environment.

## 9.6 Importance of trust

Since what people claim to be their preferences and values cannot 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 fact-check online. 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 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 date) 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 activities, kids going to school together and many other mundane activities that are not usually considered important in scientific adaptive management.

## 9.7 Examples

*** need to finish writing these examples and provide a graphic with each ***

***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 $CO_2$***

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

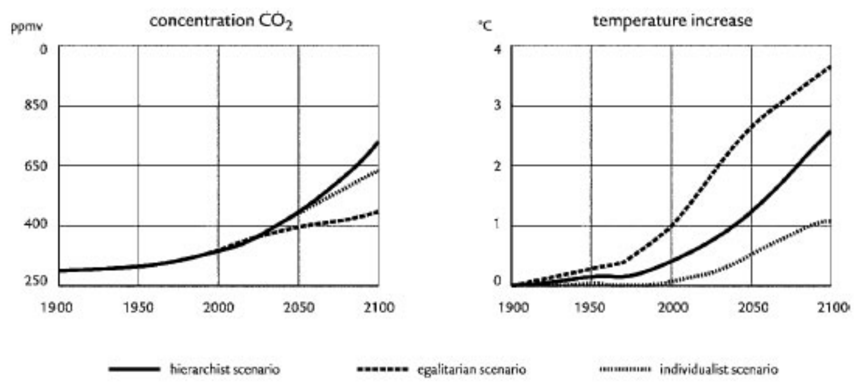



*Figure 7.* Outputs of utopian experiments in terms of $CO_2$-concentration and temperature increase.

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 an egalitarian or even hierarchical world (where there are strong destructive amplifying effects).

## 9.8 Summary

It is crucial to understand the roles of values in defining and addressing environmental problems. Individual and societal values form the basis for motivation and the key for successful implementation of any project. Environmental dialogs reveal that there are four or five prominent worldviews that are employed by different portions of the public: individualist, hierarchist, egalitarian, and fatalist. Each worldview has a self-consistent set of assumptions, value statements and preferred analytical approaches. Realizing how the components work together within any particular worldview also exposes that worldview’s weaknesses under different sets of assumptions about the future. Several examples from well-known issues (global population growth and atmospheric carbon increases) illustrate how understanding worldviews provides a very useful perspective on these problems.


# Chapter 10 - Games View of Decisions

## 10.1 Introduction

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. Strategies may be "pure", following one set of rules (strategy) to make each decision, or they might be "mixed", randomly choosing one strategy or the other. Similarly, the payout from each interaction may be a pre-determined number or the probability of a particular outcome. In this introduction to game theory, we will only use "pure" games in which you will be making selections 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 be played "against nature", in which the final outcomes are determined by the strategy that you choose and different environmental scenarios.

## 10.2 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 of looking like a copycat. The relative values for the possible outcomes will help you to determine what you should do. This is called a dilemma because no choice is optimal all the time.

Table 10-1. 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 looks cool or dorky |

In the shirt example, choosing not to wear your shirt is 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".

## 10.3 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, and 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 your neighbors 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 game matrix is given in Table 9.2.

Table 10-2: 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, you might end up with a "poor" rather than "worst" outcome, but there is also a chance you can have your "best" outcome. According to simple economics, the best 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 or when they graze. If you and your neighbor agree, there is nothing to keep another neighbor from coming in and grazing 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 make an agreement with your neighbor over the fence, there are no rules that state what you would do if he broke the agreement.

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 really an avoidable dilemma (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 assume that all common pool resources need to be converted into private properties, we should understand how to establish and tend for institutions that favor communication and cooperation.

## 10.4 Playing the game against nature and the "Precautionary Principle"

Using the same type of outcomes matrix, we can define a set of choices and a set of outcomes that depend on factors out of human control. This is called “a game against nature”. We don’t really think that nature is our opponent, but “nature” is a stand in for the concept of uncertainty of natural events. 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 all individuals might choose to do, but the most favorable choice in this situation is to take the "avoid the worst" strategy and therefore avoid any 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 that have long-term or large impacts.

Table 10-3. 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 you can't use battery power to watch your new TV |

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 a possibility that this money will be wasted. There is an opportunity for our society 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. Perhaps we can find strategies that both save energy costs and reduce the threat of global warming.

Table 10--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 |

## 10.5 Summary

This case study demonstrates the process of using a game matrix tool 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 outcomes of each possible combination of choices. Analysis of this grid can help you determine if you might want to make a decision based on avoiding the worst-case outcome, in the event that it is particularly bad, or it might help you find some other strategies that could help reduce your costs and risks.

# Chapter 11: Optimization of efficiency

Add in simple reaction, process and equipment, dynamic with regulation
Project management

## 11. 1 Introduction

"Efficiency", "optimization" and "progress" are all related concepts that are used with favorable connotations in the normal language of our industrial society. This chapter breaks down what we mean by these terms and uses these concepts to analyze all types of processes from energy transfer in ecosystems to resource use in agriculture. Although there are benefits to increasing production-- efficiency often being one of them— the assumption that efficiency is always good or that there are clearly waste products that should be reduced does not hold all the time. Especially as we attempt to apply "green" or ecological principles to industrial processes it is important that we understand that cooperative ecological communities can be more complex and less efficient than simple manufacturing. This chapter will isolate the components of efficiency and describe how this can be optimized for different types of outputs. The key point to remember is that the different products of a system (including what we may call "waste") may all be necessary; for example, optimizing the production of one product may interfere with or decrease the production of another.

To reiterate one of the themes of this book, it can be a dangerous mistake to apply a simple solution (improve efficiency) to a complex problem (ecosystem management). In this chapter I will employ more complete descriptive terms, such as "energy use efficiency" or "embedded energy" to remind you that we are being very specific. But much of the public discussion fails to, or deliberately avoids, being this specific and clear. The reasons for this are probably due to the attempt of some to put the imprimatur of engineering or science on their arguments. For example, it might sound more persuasive to argue that old growth forests are very inefficient at producing timber than it is to state that the large trees in these forests contribute a substantial amount of energy to regulating microclimate and providing a wide diversity of ecological niches. Optimization and efficiency are powerful concepts, concepts that lead to both opportunities for building new knowledge and potential for abuse.

## 11.2 Efficiency of production

The efficiency of a process is the ratio of the output to the input. This can be high or low. We should use the awkward but more descriptive compound phrase "high efficiency" or "low efficiency" to clarify that we are not assuming that "efficiency" means "high efficiency". For example, the efficiency can be calculated based on the ratio of product to the input of ingredients. The production of beer is dependent on large inputs of clean water. The efficiency of beer produced to water consumed in the process can be in the range of 1 pint of beer for 170 liters of water (1 liter of beer requires 300 liters of water in production). This is often referred to as the "embedded water" in beer, i.e. the amount of water that you are using when you consume 1 liter of beer. Another example is the amount of fertilizer needed to produce corn. For each ton of corn that is eventually harvested, it might require a minimum of *** lbs of nitrogen or *** lbs of phosphorus added. Another dimension is the amount of land used, i.e. how many tons of corn can be produced per season per acre of land. The amount of water needed to grow the crop and whether it comes from rain, existing soil water or has to be provided through irrigation is another dimension of the efficiency of production. Other factors include the amount of labor, machinery and energy to run machinery. Obviously optimizing the production of corn against land usage might require more fertilizer and water.

A commercial corn farmer has to choose how to use these resources most efficiently to get the best yield. The problem for farmers is much more complicated than just getting the ratios of water and fertilizer correct, the farmer has to consider factors relating to weather, risk of crop failure and subsidies or supports for production. However, as a commercial, for-profit enterprise, the farmer is really managing for the return on investment for growing and handling the corn. All the inputs and activities are collapsed onto a single dimension of money. This allows the farmer to make rational investment decisions and optimize the financial outcome. We must keep in mind that the business of growing corn is not maximized for corn production but rather financial return.

Many of the environmental problems will involve the same range of potential inputs, with more possible outcomes and the inability to reduce the cost of all inputs and outputs to a single monitorization. For example, a natural treatment wetland might be managed to reduce nutrient runoff from a farm, increase local biodiversity, provide crucial habitat for an endangered species, create recreation opportunities, generate employment and meet aesthetic criteria (i.e. look naturally beautiful). The owner or manager of this wetland will have all the complications of a farmer plus the added burden of making judgments about the relative value of habitat, local employment, and aesthetics. It is very unlikely the scientific basis for the management of such a wetland is derived from simply optimizing the efficiency of any part of the overall process. We will deal with the issues of tradeoffs across multiple parameters later.

## 11.3 Progress is often thought of as increased efficiency

Progress, in some sense the advancement of civilization, is often equated with the ability to use resources more efficiently to create more product. This includes the underlying idea that industrialization is able to gain access to some resources that weren't previously available. For example, modern civilization uses a huge amount of energy, and it may be argued that we use it inefficiently. On the other hand, hydropower wasn't available until we built dams, and fossil fuels have to be mined before they can be converted to fuel sources. The ability of society to employ other resources to exploit energy, mineral and water resources is a type of increased efficiency. However, we need to make this argument carefully so that it is not a simple tautology, we have more *** energy because we are able to efficiently exploit resources. Such an argument sidesteps crucial questions of motivation and values. We need to ask "why are we increasing our consumption (and dependence) on more and more energy, and how has this really improved our lives". These are not questions that can be answered with efficiency ratios, and we can't blindly assume that increased use of energy or pursuit of efficiency will be beneficial to all of us.

As we've seen elsewhere, questions like these come to the fore when comparing worldviews (chapter ***). One of the cornerstone beliefs of the Cornucopian worldview is that continued innovation will increase resource availability and lead to a growth in the economy. Similarly, the Industrial Ecologist worldview sees using the current resources more efficiently as a central factor in how we can reduce environmental impact. Thus beliefs about progress and efficiency are central to two of the major worldviews and we need to understand how these intellectual tools reinforce these beliefs.

## 11.4 Optimizing Efficiency

An optimum is when the particular set of conditions and parameters that results in the highest efficiency. This means that no other changes would increase the output and also that other conditions will be sub-optimal. In this chapter we will focus on the optimization and efficiency of processes in ecosystems and industrial processes.

Not all processes have a range of efficiencies. For example a single process in which one input is changed to one product may have the same efficiency for all conditions; any increase in the inputs leads to more products. The ratio, or efficiency of the process may stay the same and thus there is a whole family of conditions that lead to this efficiency.

Optimization of multi-step processes is much more interesting. Consider a process in which the outcome of one sub-process makes A and that combines with the output of another sub-process that makes B to make the final output C (see figure 11.1). More or less of the machinery that makes component A will make A at a faster or slower rate, respectively. The same holds for B. The optimal production efficiency is where just enough A is made to match the production rate of B. At the optimum, there is no excess machinery for either A or B. Another way of explaining this is that if there is an excess of the machinery for making A, it will make A faster than B is being produced. A little less of machinery A and a little more of machinery B would move toward optimization.

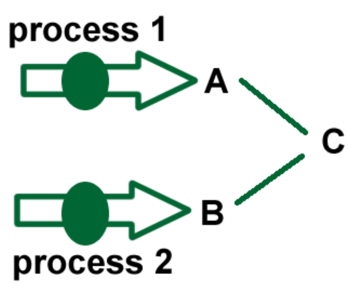



Figure 11.1 Schematic of a multi-step process. One set of machinery makes A and another set of machinery makes B. The final outcome is to use a fixed ratio of A and B to make C.

Let's consider three examples of optimization for mechanical, physiological and ecological processes.

- A familiar mechanical optimization is the construction of cars on an assembly line. Parts come in on conveyor belts to an assembly area and the workers attach new parts to the growing automobile. The optimal speed to put on new bumpers is to get one set for each car. Running the bumper conveyor belt faster doesn't create cars faster; in fact, it may interfere with the assembly line and slow down the whole process.
- In plant physiology, light trapping reactions in the chloroplast are matched to the process of fixing carbon dioxide into organic compounds such as sugar. The light harvesting reactions provide the high-energy intermediate compounds that are used in a particular ratio by the enzymatic pathway that reduces CO2 to trioses. Plants that grow in low light environments will have more pigments to trap more of the available light and plants that grow in high light will have more enzymes to process CO2 into trioses. The low and high light adaptations represent optimization strategies to use the available resources in the most efficient manner possible.
- Ecological systems such as grasslands are very efficient at capturing solar energy and converting that energy to new biomass. One of the tradeoffs that determine their efficiency is the amount of water that these plants transport from the soil to the air compared to the amount of energy captured for photosynthesis. If there is abundant water, the grasses will move more water that brings in more nutrients from the soil and supports higher net growth. If water is limited, for example during a dry period, the plants will close down their stomata which leads to less water transport and less nutrient transport and slower growth. However, the shift in plants from those that do well in wet conditions to those that do better in dry conditions results in far more growth than if the "water loving" plants were just grown with less water. This bonus is the consequence of

shifting to a more efficient use of water during dry conditions.

These examples illustrate how we can describe the use of resources and machinery in ways that increase efficiency and tend toward optimization. Whereas the oversight of a factor should attempt to be as efficient as possible, please don't jump to the conclusion that plants or wetlands only operate with a goal of simple optimization. We will discuss the limits to optimization later.

## 11.5 Dynamic Optimization

As discussed above, the optimal allocation of machinery or biosynthetic components to a process or biological pathway results in a balance of intermediate products so as to just meet the need for creating the final product. If there were one set of conditions and resources, then there would be one optimal ratio of all of the components necessary to turn those resources into the final product. However, there is often a constantly changing composition of resources and turnover in the machinery or biosynthetic components. In these situations, we need to understand the process of dynamic optimization, which continually adjusts the process toward a better or more optimal ratio of resources and machinery.

Replacement and reinvestment cycles are a crucial part of dynamic optimization. In mechanical systems, machinery can wear out and need to be replaced or the machinery can be removed and replaced. In either situation, management can either decide to increase or decrease the capacity of those particular machines or to shift investment to some other part of the processing. For example, if an automobile factory has too much machinery for making car bumpers, when one machine wears out they can manage toward more optimal balance by not replacing it at all. This same logic drives the algorithms evident in biological systems. If a plant has too much light harvesting membrane and pigment, new growth will have higher investments in carbon fixation enzymes. Some biological systems also have the potential for breaking down current components to molecular building blocks and resynthesizing new components (the Lego model). This extreme version of dynamic optimization is most often found in stress response systems and not used as a matter of normal vegetative growth, simply because there is a high energy cost to breaking down proteins and then resynthesizing the amino acids into new proteins. Continual growth and turnover provide a favorable framework for dynamic adjustments and optimization.

A simple algorithm for optimization depends on tracking the intermediates in the chain of production or biosynthesis. For example, as seen in Figure 11.2, if component A builds up, that means there is too much A being produced. Shifting the investment to favor making more of the machinery for process 2 will help the system catch up by making more B. The reinvestment could be from the profits created by selling the product (C). In biological systems, the production of building blocks will be allocated to biosynthesis of proteins and lipids that make up the machinery of the processes. For example, the balance of photosynthesis between light-harvesting reactions and enzymatic synthesis of fixed, organic carbon molecules are tightly controlled by the build up of the high-energy intermediates (NADPH and ATP) that are created in the light-harvesting reactions. If these are too high, synthesis of new enzymes is stimulated. The details of biosynthesis regulation is much more complicated than this, but this is the underlying logic of the algorithm.

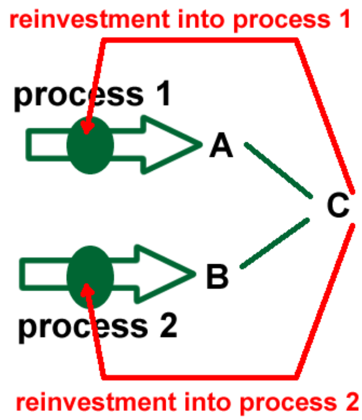



Figure 11-2. Dynamic reinvestment algorithm for a system with two processes.

Dynamic optimization must deal with time lags and threshold responses. Time lags occur between the time a signal is detected until the system can react. Take, for example, a supply chain. By the time the store realizes that it doesn't have enough beer, it's already too late to order more from the distributor who passes orders on to the brewery. This particular example is the key to the famous beer game simulation. If you are playing the part of the retail outlet, you have to predict the demand for beer and order ahead of time in order to smooth out wild oscillations that can occur if you order late, end up with too much beer on hand, and then wait until the supply decreases to order again. In these cycles, the system becomes inefficient due to the wild oscillations in product levels. More complex algorithms are required to manage systems that are susceptible to such oscillations, and some of these algorithms employ multi-scale strategies that smooth out the process over time. These strategies are not strictly optimal at any one point in time, but do very well over longer periods and through fluctuations in conditions. The previous examples show that optimization algorithms are challenged by linear resource regimes and the assumption of linearity is even worse in regimes that contain thresholds. A threshold might be something like a potential dramatic loss of a particular resource. Often it is simple optimization algorithms that drive systems over the thresholds. Complex resource availability or uncertainty requires a shift to resilient strategies rather than strictly optimization.

## 11.6 Biological models and metaphors

Biological models are often used as models for efficiency based on the appreciation for the benefits of long-term natural selection in the highly complex natural world. There are three lessons we can learn from this comparison: 1) it is not possible to be strictly optimal for all conditions, i.e. there is no “super organism”, 2) tight coupling in regulation and multiple levels drive biological regulation but come at a significant cost, and 3) extrapolating from biological systems to human management strategies is dangerous because the context is so different. First, in the biological world, “costs” are the losses from being less than fully competitive, and this drives the need for improved efficiency. Individual situations and sets of parameters favor particular efficient solutions, but there is no one solution that is best under all conditions. This is a consequence of the nature of optimization; if there is an optimum (rather than a broad spectrum of conditions that lead to the same output), then changes in the conditions will lead to a sub-optimal condition. For example, this explains why there can’t be a “super algae” that is most competitive at low light and at high light. At low light, the algal cells need more pigments and fewer enzymes, and at high light, the reverse is true. If an algal strain has high pigments and high enzymes, then at low light another strain with fewer enzymes would be more efficient and grow faster. Second, biological systems are tightly controlled through the coupling of processes and embedded regulation. Regulation of biological metabolism is keyed to several global variables as well as the idiosyncrasies of each reaction. For example, enzyme reactions in photosynthesis are dependent on the cell-level availability of the reductant NADPH, the local concentration of the substrates for the reaction (including NADPH again), the ion content of the local solution and the specific location of the enzyme relative to other enzymes. Thus there are at least four levels of control that have differing time and space scales. Another example is the regulation of human body temperature. This is often compared to a thermostat, which is a gross understatement of the complexity of this bodily process. If you are exposed to higher ambient temperature, you respond at five different time and space scales (Table 11.1)– you don't just turn on and off a heating or cooling mechanism.

Table 11-1: Five overlapping mechanism for the human response to increased heat.

1. Skin flushing with more blood near the skin
2. More blood flow in general
3. Sweating
4. Increased breathing rate, i.e. ventilation
5. Behavior such as fanning yourself or moving to shade

These mechanisms for control are all embedded into the overall physiology of the organism and take energy to maintain. The "goal" of regulation isn't to optimize but rather to survive a broad range of conditions, to live in a smaller range and thrive in a narrower range still. Regulation needs to guarantee survival first, resiliency next and optimization or expansion last. The lesson from biological systems is that there are broad areas of inefficiency that must be tolerated in order to maximize survival either of the individual, population, or species globally. The third lesson from studying biological systems is that we need to be very careful about extracting small bits of the mechanism and generalizing to human processes. I call this "fracturing the metaphor", in which the full context is abandoned to make a point. The most common and pernicious example of this is to extract one aspect of biological evolution, "survival of the fittest", and extend this to social and management activities. An example of a fractured metaphor is how biological evolution is used a metaphor for efficiency, when the metaphor should really be limited to the competition that takes place within the entire process of evolution. Biological evolution is the outcome from three inter-related mechanisms that must work together. These three parts are: 1) competition in which fitness is expressed through more offspring, 2) barriers to over-production such that no one solution will immediately wipe out all potential diversity in the current population, and 3) mechanisms to continually generate new diversity in the population. In animals and plants, mechanism 2 is accomplished by having multiple alleles for each gene in the population, and mechanism 3 results from sexual reproduction (and to a lesser extent mutations) that continually mix and provide new versions of gene combinations. In the "fractured metaphor", the power of natural selection is a loaded onto the fitness function and this is over-extrapolated to be a natural law that should apply to human social and economic systems. Instead, natural selection is much messier and two of the crucial components that make it work are related to sex. You'd think people would be more interested in sex. There is a wealth of knowledge that we can gather by studying the regulation and optimization of relevant biological systems and one of the key points should be to learn how to transpose the understanding of complexity to human systems, not to extract simple snippets that can be dangerously oversimplified.

## 11.7 Multi-parameter optimization

Optimization of processes that involve multiple parameters is a challenge of seeking efficiency among the tradeoffs. For any particular input, there could be an optimum relative to the other factors but there is no joint optimal point. For example, if we are growing tomatoes in a greenhouse, there could be an optimum output of tomatoes for water relative to the light, a different optimum light level relative to the fertilizer added and a third optimum ratio for fertilizer in relationship to the water. There is no guarantee that there will be a single optimum for water, light and fertilizer. If, as we saw for corn production, everything can be collapsed onto the amount of money you spend for the resources and the profit, then it is easy for the grower to find the best cost-effective solution. However, in similar ecosystem restoration and ecological problems there may be no comparable cost structure for work put in, resources used and output. For example, if restoring a wetland, how does one compare the values of local employment, water quality improvements, bird diversity, fish habitat, and recreation opportunity? Economists are trying to develop methods that will help support these decisions, but these methods are still going to seek tradeoffs, not optimization. We are faced with these sorts of tradeoffs all the time in agriculture and ecosystem restoration. What is the appropriate allocation of water, energy, materials (such as fertilizer), land and labor? Or put another way, what is the distribution of forms of capital between natural capital (water, land), built capital (machinery and infrastructure), human capital (labor and know-how) and the expenses of operation (for example energy)? Industrial, large-scale organic, high-intensity and artisanal farming enterprises all reach different viable mixes of these forms of capital and expenses. Ecosystem restoration and management activities are faced with the same set of choices on inputs but also challenged by a range of possible outputs between social, ecological and economic products. For example, a lake could be restored by installing small wetlands requiring consistent local labor and natural capital, or the lake could be restored by contracting with a large external firm to come in and treat the lake. The choice between these is not clear, and it would be difficult to make a good decision without considering how the project would impact the local community. Optimization, or looking for the most cost-effective solution, may miss the opportunity to bring real benefits to this community.

## 11.8 Limits to efficiency

Natural limits to the efficiency of any process lead to diminishing returns on effort and investment. If a process has been optimized for the ratio and amount of inputs, it will take increasingly more effort to provide those inputs at higher and higher rates, i.e. each increment of increase in the production requires an even higher increment in the effort to supply the inputs. This is the law of diminishing marginal returns, and it is a crucial consideration in the limits to optimization. A simple example is the spiral of increases that need to take place for a plant to grow faster than its optimum; more light needs to be intercepted, but as the plant gets more leaves, the upper leaves will shade lower leaves. In addition even more leaves will require more water has to be transported, which means more tissues in the stems and the roots to collect and transport the water. Each increment in growth rate requires a more than a linear increase in the supply chain, with increasing inefficiency. Another aspect of diminishing returns is the increased demand for regulation as the process is stressed, which often leads to more complex regulation strategies and higher operating costs. Increasing regulatory costs with industrial expansion has been proposed to be the reason that developed countries have such high levels of government regulations (Adams 1988), and the increase in complexity with the growth of societies has been proposed to be one of the major contributing factors to the collapse of civilizations (Tainter 1988). Thus the decrease in marginal return is not just an academic exercise that pertains to small environmental projects trying to get bigger. There are two important concepts that relate diminishing marginal returns to economic markets. The first is called the “rebound effect” (Hertwich 2005), also know as Jevon’s Paradox (http://www.eoearth.org/view/article/155666/). This principle states that increasing the efficiency of any particular component of a process will result in more use of that parameter. For example, making aluminum recycling more efficient led to an increase in the use of aluminum. Similarly, increasing energy efficiency of industrial motors actually increases the use of energy. In both cases, increased efficiency led to that resource becoming cheaper and thus a market force, profitability, overshadows the environmental effort to reduce consumption. There is a similar economic principle that states that profit maximization will be at the point where marginal revenue equals marginal cost. Increasing the efficiency of a component lowers the marginal cost and thus will lead to more production. Both of these related principles illustrate the gap between optimizing a process that in turn reduces environmental impact and optimizing the process in a market-driven situation. The law of diminishing returns often pits market mechanisms against good environmental planning.

## 11.9 Analysis to improve and optimize efficiency

A straightforward approach to analyzing the efficiency of any process starts by determining the scope and extent of your study that would be included in the life-cycle of the process or product. This is essentially a systems approach. Second, you need to identify all the initial inputs and the final products. This depends on how far back and how far forward you want to go in the production, i.e. which components do you start with and what are the final products? For example if you are studying the life cycle of cars you might want to start from the mines that produce iron and aluminum all the way to the recycling of the cars back to these base-level components. Or if you are studying food, you might be able to assume the final outcome for food will be the same, and you can focus on comparing the starting production. Third, after you have identified all the inputs and outputs, then you need to identify all the internal processes that can be controlled or invested in separately. Again this is an exercise in which you might want to lump or separate processes depending on your intended goal. The forth step is to determine the tradeoff factors for the controlling factors. If this is a strictly economic/market exercise, this means monitorizing all the components into dollars. If this is a socio-ecological project, you will then be faced with a more daunting task of determining relative values for inputs and outcomes. Stating your assumptions on the relative value as objectively as possible is often the only real choice at this step. For example, you might conclude that creating wetlands will, in addition to meeting the goals of the project, create more local jobs but treatment of the lake with an industrial method might lessen the disruption on the local recreation industry. Again, value statements are a key part of our work and the evaluation of relative value claims is best left up to the community, not obscured in the equations of a management model.

## 11.10 Summary

Efficiency, optimization, progress and growth are inter-related concepts in our industrial society. We need to unpack these concepts, study them and re-apply our knowledge to environmental problems. Biological models and metaphors, when taken in their full messiness, demonstrate that the costs of increased production are often related to more complex and embedded regulation. A systems approach illuminates how the law of diminishing marginal returns is the flip side of optimization, and that there will be increasing costs to pay for any growth past the optimum. In fact, in many cases the optimum for environmental health may be quite below the resource consumption level that would be reached by an efficient profit-seeking market, even if all the externalities are included!

Add in above

This is because of the nature of profits being the integration of the efficiency and costs of all goods produced rather than a point of optimal production. Life cycle analysis that includes the tools from systems and accounting is a valuable approach to all environmental problems.


# Chapter 12: Sustainable Institutions

## 12.1 Introduction

A range of institutions necessary for environmental management

All environmental problems contain natural and human components. Addressing these problems will require working with ecological constraints, scientific knowledge and social structures. These can be viewed as the "rules" that are in practice in a particular situation. Rules in practice are institutions (reference). When we address rules that govern environmental problems and what we need to do about them, we are either creating or modifying institutions. In this section we will view institutions as a social constructions that allow us to integrate both knowledge-generating frameworks (such as the "systems" and "network" views presented earlier) and decision-making frameworks (such as the "games" framework). In this view, the purpose of an institution is to serve as a vehicle to solve an environmental problem by bringing together appropriate information and decision-making skills.

As we discussed in Chapter 1, environmental problems can be characterized by either their alignment between costs and benefits or by their complexity (Figure 1-1). This categorization of problems shows that not all problems can be solved by collecting more information or applying more regulations. In particular, wicked problems require political involvement, community- and consensus-building processes that may take a long time and require substantial resources.

Of immediate interest is whether the problem is being solved to meet some external requirement or for the benefit of the members of the group. In small groups of people or groups of organizations, the formation and organization of these has been characterized as either "work groups" or "clubs" (Arrow et al. 2000). This distinction forms an important constraint on the ability to change the rules, to modify the institution itself, in response to the problem. Externally formed groups are more likely to work within the rules of the institution. On the other hand a self-contained club can change the rules but might not have any other social or economic capital to draw on. This is the classic tradeoff between authority and flexibility.

## 12.2 Example institutions in the background

Several simple examples illustrate the embedded, almost background role that institutions play in solving environmental problems. The recycling of beverage containers makes sense because of diminished energy costs (especially for aluminum cans), reduced litter and pollution, and minimized effort on behalf of the consumer who is returning to the store anyway. However straightforward you might think this is, it took the creation of an agreement between many parties, i.e. an institution, to make recycling work. In Oregon, one of the first states to have a bottle bill, the institution involves grocery store owners collecting the deposit from shoppers; some of the deposit goes directly to the store and some goes to an industry group overseeing the deposit, some of it goes back to the consumers when then return bottles and cans. The reason this works is that the store and industry group gets to keep unclaimed deposits. Unclaimed deposits are really a tax on shoppers who don’t make the effort or who can’t return the cans and bottles for some other reason. Even in a place as environmentally conscious as Oregon, this turns out to be a lot of money. So for all the civic pride in having a bottle bill, the recycling program may actually work (i.e. be profitable to the stores) because enough Oregonians don’t recycle.

Carbon credits are another example where there has to be institutional infrastructure in the background for this to work. The media has paid a lot of attention to the amount of money that might change hands for carbon credits in which an energy company in the USA (that emits excess carbon dioxide) might pay some entity in the Amazon for protecting forests (that sequester carbon dioxide). In order for any such an exchange of money to take place, there needs to be a bank for carbon credits that verifies the carbon sequestration amounts and securitizes these into a certain number of credits. The bank also has to establish some method for dealing with the risk involved with natural resources, such as from fires or other natural disasters. In addition to carbon trading, there are similar banks for wetlands and pollutants.

## 12.3 Creating institutions to deal with CPR

It is important to establish that institutions, sets of rules, can resolve environmental and resource problems and, in particular, that CPR problems can and have been solved successfully without resorting to either overwhelming exogenous force (federal intervention) or privitization (turing a common resource into a private resource). This observation (by Ostrom and others) contradicts the simple analysis proposed by Hardin, i.e. that a tragedy will occur unless strong, external governance protects the commons. The following examples presented by Ostrom (1990) illustrate the design principles that are characteristic of successful CPR institutions.

Add in from –

Ostrom-2005.html

Ostrom_and_Walker_1997.html

## 12.4 Innovations require new institutions

see Homer-Dixon

## 12.5 Governance forms as institutions

Democracy – tenets

SAM as a internal regulation institution

Conflict between science and democracy

See democracy-SAM folder

See section in NALMS 2012 talk

## 12.6 Summary

many institutions are required
need to fit the purpose
maybe in the background
CPR is good example
Governance institutions are not necessarily matched to current environmental demands, however good environmental stewardship may lead to good governance


# Chapter 13: Scientific Adaptive Management

## 13.1 Introduction

The management of natural resources faced a major challenge due to industrialization of our global society because human activities had enough power to overwhelm natural ecosystems. According to Walters (1986), there were two major flaws in resource sciences: “only token consideration [was] given to the socioeconomic dynamics that are never completely controlled by management activities”, and second, there was no strategic method to deal with the large degree of uncertainty. Scientific adaptive management (SAM) deals with both of these issues. SAM is a “continual learning process that cannot conveniently be separated into functions like “research”, and “ongoing regulatory activities”” (Walters 1986) and blends these into a single process in which management manipulations are designed as experiments that will provide information for better future management. Scientific adaptive management is framed in the decision-making context with an emphasis on addressing and reducing uncertainty through continual management activities that will change as the organization learns more about the functioning of the ecosystem. This process is scientific because it requires rigorous pursuit of new knowledge. It is adaptive because the activities change as the organization learns more. And it is managerial because it depends on human manipulation of the environment. Scientific adaptive management is the integration of research driven control strategies as a strategic approach where management effort is used to generate experiments and the experiments inform ongoing management. It is not just trial and error in which a new approach is tried when the previous one failed. Trial and error does not have the intentional strategy behind each trial.

Fisheries management is a good example of the difference between reactive management and adaptive management. There is a major degree of uncertainty in the estimates of the salmon population growth in the Frasier River, BC, Canada. For instance, it is unclear if more salmon leads to more spawning or if it leads to repression due to competition. The adaptive management approach proposed by Walters (1986) would be to allow more salmon to return up-river and then follow what happens to the spawning and production of smolt. The management approach requires a limit on fishing for a period of time, but it could lead to a better understanding of the population biology of salmon and better management of this resource. Even though SAM provides the potential for better management through learning, there were two objections to this approach. First, the salmon fishing industry didn't want to limit fishing and believed that the stock was already being managed well. The agency would lose the public's confidence if they stated that there was so much uncertainty over basic questions of salmon biology. Second, there was an underlying belief that the uncertainty over fishing pressure and yields could be resolved with less drastic approaches such as scientific research. Employing scientific management would require them to explicitly acknowledge that real pressure on the fisheries from harvesting was necessary to actually understand how fish reproduction, survival and fishing all were inter-related. That acknowledgement was the same as admitting that pure science and modeling couldn't provide answers in this complex system.

The concepts in scientific adaptive management are built on a strong ethical and philosophical foundation.

Leopold –

Norton –

This chapter will define and outline the strategic process of scientific adaptive management. It will then describe the conditions where SAM is needed and where it can contribute to solving environmental problems. This discussion builds on what you've already learned about the how the dimensions of controllability, uncertainty, and values determine possible modes of engagement. Then the specific tenets of SAM will be provided and related to several examples from forests, lakes and fishery management. This chapter will also illustrate how SAM deals with uncertainty and the problem of values in science. As you will soon understand, scientific adaptive management requires strong, functional institutions and management. An important aspect of scientific adaptive management is how it both compliments and conflicts with the democracy. Finally, this chapter will illustrate how scientific adaptive management is an essential strategy for addressing how societies can learn to be sustainable.

More than any other topic in this book, the discussion of scientific adaptive management must address the role of values in environmental science. On one hand, there is the widely held view that science and scientists should be objective and that scientists should produce objective knowledge to be handed over to policy makers. This was codified in the EPA's risk assessment and risk management programs that were not only done separately but housed in different towers at their headquarters (Norton 2005). A recent modification of this approach has been described by Pielke (2007) in which he argues that science is best suited to creating policy alternatives, while staying out of the decision-making process. He calls this role for the environmental scientist the "Honest Broker of Policy Alternatives". On the other hand, some proponents argue that those who are most knowledgeable about any particular ecosystem issue should be directly involved in policy. This role is often called an "activist-scientist". Norton explains that in the scientific adaptive management process, all evidence must be presented, assumptions laid out, and values stated. In this mode of full-disclosure, "pre-experiential commitments" i.e. ideological biases are removed. My feeling is that since values are a central part of environmental problems, scientists must learn to deal with values and worldviews. This is an exciting and open question that you can address for yourself.

## 13.2 Conditions when SAM is employed

Scientific adaptive management is one of the major tools that we have to engage with large environmental problems that are large and have long time horizons. Because of the increase in population, energy use, and affluence our impact is large and growing. According to Lee (1993) “The rate of change is outstripping the ability of scientific disciplines and our current capabilities to assess and advise” society on reasonable management strategies using traditional methods. We need to use continual experimentation and organizational learning to address these problems. As Norton states (2005), “We are now living in the age of culture: humans today must learn very rapidly, because our impacts on nature are accelerating at the rapid pace of Lamarkian cultural evolution…long-term survival will be determined not by our ability to transform our environment quickly, but by our ability to quickly react to a more rapidly changing environment.” Both of these authors, Lee and Norton, see adaptive strategies as the only way to rigorously and effectively address the management challenges of dealing with rapid change and uncertainty.

The official Department of Interior description of scientific adaptive management provides a typology for problems that should be addressed (Figure 19.1). This is very similar to our CUV treatment minus the value axis. This manual also lists two key conditions that must be met for SAM: 1) a mandate to take action in the face of uncertainty, and 2) the institutional capacity and commitment to take on the problem. There are also six characteristics that contribute to the success of SAM: 1) it must be a real choice with substantial consequences, 2) there must be the opportunity to apply learning in subsequent iterations, 3) clear and measurable objectives have to be created, 4) good information has high value, 5) the uncertainty needs to be represented by sets of conflicting models, and 6) data collection and analysis of monitoring has to lead to reducing uncertainty (i.e. it can’t have overwhelming, irreducible uncertainty). If these two conditions and six characteristics are met and well managed, learning organizations can make progress toward solutions of large environmental problems.

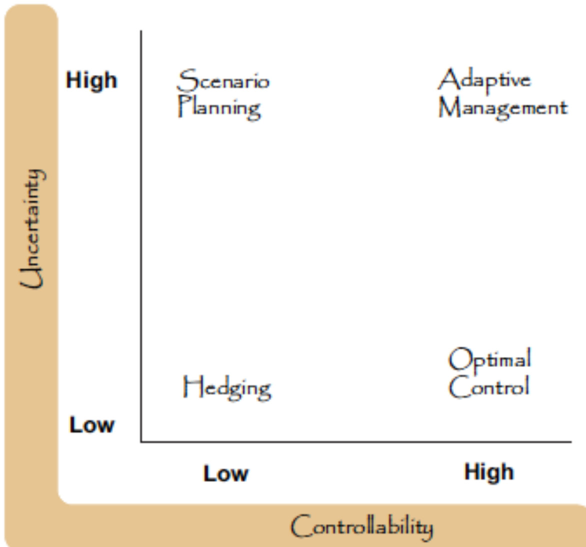



Figure 19.1 Approaches to environmental problems based on controllability and uncertainty. Source is DOI (****).
Adaptive management must be able to deal with fluctuations in the environment at different space and time scales. Healthy ecosystems should be expected to demonstrate a dynamic behavior that "continuously generate and relax tension on a continuum of scales" (Pahl-Wostl 1998). Management schemes can't just exert control to fix a single problem but must attempt to build resilience, i.e. increase the health of the ecosystem. A good example of this is how forest fires are managed by promoting many small fires of different sizes and shapes with the goal to reduce the chances of large, mega-fires. Mimicking the natural processes that lead to the forest mosaic takes a dynamic management style rather than a single prescription or simple outcome. The fluid nature of long-term adaptive management allows setting big goals (such as

reducing large fires) and using small-scale management activities as both tests of how the system works and as measures of control.

## 13.3 Tenets of Scientific Adaptive Management

Norton (2005) lays out the three tenets of scientific adaptive management as: 1) experimentalism, 2) multiscalar analysis, and 3) place sensitivity. Experimentalism emphasizes using management as experiments and taking actions that serve both for control but also to learn how the ecosystem works and reduce the uncertainty for future actions. The principle of multiscalar analysis requires managers to use models to understand how the ecosystem works over a range of space and time scales. This tenet is one of the key aspects of using SAM to seek sustainability and will be discussed later in the chapter. The final tenet, place sensitivity, acknowledges that each site of management is a unique spot on Earth with its own history and set of complex processes that have led to the current state. This third tenet stresses the importance of approaching these systems as individual cases and tempering the use of broad simplifying generalizations.

The three tenets support each other philosophically and, in practice, result in the expression of the "land ethic" of Aldo Leopold. Simultaneously relying only on evidence that can be gathered on a particular ecosystem, thinking "like a mountain" over the long term (as Leopold suggests), and approaching each location with respect as a special and complex situation will lead to deeper understanding. These multiple perspectives work together to provide the rich narrative required for generating management hypotheses that do justice to the place. But the discipline of mind required to keep these different perspectives in play and reach a creative solution, i.e. there will be management action, not just theorizing, and these three tenets and the ethic guide that adaptive management process.

## 13.4 Examples of scientific adaptive management

Dealing with a dynamic ecosystem: Glen Canyon Dam (Meffe 2002)

- Water releases as experiments
- Tradeoff between power generation and ecosystem health
- Changes in practices during management

Probing population responses: Idaho Elk Management (Meffe 2002)

- Gap in knowledge about population size and growth rate
- Different hunting rates in different areas as experiments

Management of a complex socio-economic system: Columbia River Basin (Lee 1993)

- Many jurisdictions and stakeholders
- Bringing in the values

Counter example: *** trial and error, then reformulation **

- Decide on a solution
- Implement that solution
- Later – figure out it didn't work and go back to the drawing board

## 13.5 How SAM deals with uncertainty

Scientific adaptive management acknowledges that uncertainty is a major obstacle to management strategies and differentiates between uncertainty and risk. Uncertainty can't be reduced to a simple probability of outcomes. Such is the nature of risk. In cases where risk can be managed using a portfolio of diversified approaches (i.e. hedging) is a more appropriate strategy (see Chapter 17). Scientific adaptive management deals with the three components of uncertainty (Chapter 9): ignorance, surprise and volition in three ways. First, when management actions are used as experiments, this will mainly decrease or delimit the ignorance component, i.e. what we don't know about the system. Second, having a long-term plan for how to handle the results of these experiments and taking a broad, multiple-perspective view lays the groundwork for dealing with surprises, i.e. qualitatively different outcomes than expected. Finally, SAM, in practice, has many features that deal with the unpredictability of the human dimension. A wide range of stakeholders can be brought into management discussions as long as they provide evidence for their viewpoints, agree to a democratic process (discussed later) and specify their values that they are willing to discuss. Scientific adaptive management provides a platform for promoting pluralistic discussions that can lead to improvement of organization function.

The process of SAM often employs devices and technologies that help promote the inclusion of many ideas and values (Meffe et al 2002). The holistic approach includes many people and is essentially pluralistic, actively seeking more input for the whole range of stakeholders and participants. Simulations or scenarios are often used to engage discussion on possible outcomes and get technical and public input on different potential outcomes. For example, simulating the effects of current choices over several decades is a valuable tool for engaging them in the discussion. Furthermore, decision criteria that are formulated in a way that are flexible, preserve future options and graded (i.e. not all-or-nothing) are not only characteristic of SAM but also help to involve public discussion without causing unnecessary strife over an ideological divide. For example the "safe minimum standard" (SMS) decision criteria states that an action should be taken if it has little chance of causing damage and is affordable **check this statement **. SMS is also graded by scale where a small and rapidly reversible action is more likely to meet the standard than an ecosystem scale approach that might take many decades to reverse. The outcome of the SAM process is to promote community and organizational learning that is fast and directed as opposed to tradition (which doesn't change) or trial and error (which is very slow) (Meffe et al. 2002). Thus the process should be attractive and rewarding for those citizens and interest groups that fully participate.

## 13.6 How scientific adaptive management deals with values

Scientific adaptive management is fundamentally based on value-laden, mission-driven science (rather than curiosity-based). This approach is suited for wicked problems that are inherently complicated by always changing information and values. A specific aspect of SAM (as described by Norton 2005) that addresses human values is the differentiation between considered and held values. Participants need to identify which values they are willing to consider changing in light of evidence and which they are unwilling to change in the face of any evidence. Identifying the assumptions that lead to people's considered values is a useful step in determining what evidence is required to make a change. Scientific adaptive management uses several tools that deal with values including:

- More here
- Scenarios
- Risk and uncertainty
- Consultancy
- Pielke 2007 – honest broker of alternatives

## 13.7 Control and the importance of institutions

Initial implementation and control of large projects require communities to use existing or new institutions to communicate and make decisions. Scientific adaptive management is most useful in large space and longer time scales. These large projects shift how we think about the world from the concreteness of a particular place to the abstractions involved in large (such as basin scale or forest ecosystem) concepts that deal with the future. Communities use institutions, such as state or local governments, to deal with these abstractions, in particular the uncertainty of the future. SAM is a process that attempts to control the future and must be situated in an organizations that is able to look to the future. As Nabokov said, "what can be controlled is never completely real; what is real can never be completely controlled." A major risk in all large projects is that the uncertainty and lack of concreteness can lead to large unintended consequences. Pielke (2007) warns that any project that is big enough to be considered as a panacea for all problems is “also big enough, and more likely, to produce unintended consequences of catastrophic dimensions.”

Managing large, complicated projects requires strong and high-functioning institutions that use best practices. Control of human-nature coupled systems are difficult enough to conceive as a static process, and the goal of managing for dynamic resilience is a challenge to management practice. Mechanistic metaphors and feedback control that depend on cause-and-effect mechanisms have to be discarded in favor of dynamic systems that are always poised at the edge of chaos (Pahl-Wostl 1998). Managing in this zone means that the problem is only partially structured at any time and the management effort must be constantly innovating or improvising (Brown and Eisenhardt 1998). Improvisation and innovation (as we saw in Chapter 15) can be supported by identifying the larger goals while restricting the number of specific operational rules to a minimum. The only way to do this is to have organizations that are designed for the function of learning. These institutions acknowledge uncertainty as a major component of the problem, allocate effort to training people, reward experimentation and possible failure and recognize the importance of surprises as opportunities for learning (DOI ****).

- add in
- Double loop learning
- Setting objectives
- Refer to chapter 17 – optimal management strategies

Constantly improving environmental regulations and policies and dealing with the related politics are addressed using scientific adaptive management. For many of the reasons addressed above, but particularly the uncertainty due to changing human preferences, SAM provides a robust and objective framework within which environmental scientists can interact with politics. Lee (1993) advises “The strategy I urge – to be idealistic about science and pragmatic about politics”. Science is designed to find facts and be able to objectively represent gains in knowledge to be reviewed by peers. Politics aims to use power responsibly, i.e. in an accountable manner. Thus both science and politics are beholden to accountability, but to different audiences. The degree of involvement of technical experts and scientists in policy making is an active area of debate, but they are participating whether directly (as an activist) or indirectly (providing arms length advice). Large environmental projects require inherently politically strong and forward-looking institutions that operate effectively.

Scientific adaptive management is most often associated with the political institution or democracy. Like our general conception of democracy, SAM is a process that attempts to bring in many points of view, encourages the participation of many and works toward a fair and just outcome. Norton specifically proposes that all participants in a scientific adaptive management process be committed to the democratic process (Norton 2005). A potential major challenge to good environmental management is the requirement for policy to be based on cause-and-effect mechanisms, i.e. if pollution causes fish kills, then we will pass regulations to reduce pollution. Democratic processes may help deal with uncertainty in some situations by bringing more ideas to the table and providing a framework in which the participants trust that the outcome will be fair and just. This framework of trust is also crucial for allow time to work through periods of ambiguity and contradiction. However, democratic processes can also stall that same flow by serving as a mechanism for pure interest group pluralism, i.e. only interest groups not the public get to provide new options (Pielke 2007). It is important to consider where democracy and SAM reinforce each other positively, are in conflict and reinforce each other negatively (Table 19.1). In this treatment we are considering the liberal form of democracy in which the majority rules but also protects the freedoms of the minority.

Table 19.1 Alignment of the institutions of scientific adaptive management and liberal democracy.

| | |
|---|---|
| Positive reinforcement | • Democracy generates many options |
| In conflict | • Democracy can't impinge on the rights of individuals, but it is often the definition of these rights (water, land use, etc) that is the center of the debate for environmental issues<br>• Large scale environmental issues require infrastructure (i.e. agency/bureaucracy) which has been called the "double state".<br>• Democratic public debate has difficulty dealing with issues that don't have a clear "cause-and-effect" relationship. Sophisticated and expensive SAM can address this |
| Negative reinforcement | • Both have trouble when there aren't clear objectives<br>• Differences in values that persist after problem definition<br>• Wicked problems in which the problem morphs as more information is gained |

Aggressive efforts to manage environmental problems at the level of pragmatic stewardship proposed by Leopold (****) can lead to overall better governance. Most complex and wicked problems that a community addresses require institutions that can manage balancing individual vs. community values and planning for an uncertain future. If the community agrees on solving an environmental problem because they see that doing so is valuable to all individuals, the same institutional framework can be used for governance of other community issues. The claim is that good environmental stewardship can lead to better governance.

- Putnam – trust, commerce, democracy
- Cooperative win/win as described even in non-democratic societies Mersini 2002
- Portland example – Steve Johnson – watershed agreement

As was presented in Chapter 15, innovations such as scientific adaptive management processes require concomitant institutions to implement and control innovations. For example, if we export innovative environmental methods to developing countries, these will go hand-in-hand with stronger and more competent forms of governance. This has been the experience of the US Peace Corps and other environmental NGOs, and democratic community processes should be considered a benefit of our environmental actions.

## 13.8 Sustainability

As described above, scientific adaptive management is a process that can be implemented by effective and forward-looking governance institutions. This combination of evidence-based environmental decisions and democratic processes are exactly what we need in the discussion of sustainability. Too much of the sustainability push is to determine which particular outcomes we need. Although specific goals (such as 350 ppm $CO_2$, zero population growth, or target Gini coefficients) are useful for rallying popular support, they don't describe how we will get to those targets or the forms of cooperative governance that will be required. Norton (2005) is very clear in his call for using SAM to address the science and values of sustainability. Currently, the dominant paradigm is the so-called "grand simplification", which states that since we don't know which forms of capital (human, built, financial or natural) future generations will value most, the best we can do is to pass on to the future a world with maximized total capital. This "weak sustainability" argument assumes that all forms of capital are exchangeable and that more capital is always better. Scientific adaptive management of the future accumulation of capital would require that the values of all of these forms be explicitly identified and that any assumptions about these different forms be tested objectively on the basis of evidence (not ideology). The SAM approach to the future, although it may seem incongruent with sustainability, would require many small experiments and continual adaptation to match the proper scale and speed necessary to maintain the parts of our world that we value (Thiele 2011). The argument for small scale experiments was laid out *** years ago by Schumacher **1975**) in “Small is Beautiful”; “There is wisdom in smallness if only on account of smallness and patchiness of human knowledge, which relies on experiment far more than on understanding.” And more recently under the banner of localization that describes the two paths necessary to approach sustainability, “One path is on-the-ground practices. . .The second path builds in part on these many small experiments and their accumulating knowledge” (de Young and Princen, 2012). The authors continue to describe how this will form a base for political action at the local, community level: "People need to be engaged in a process, the details of which cannot be worked out by others, certainly not by decision makers far removed from people's everyday existence." Thus, even though the main thrust of the discussion in this chapter on scientific adaptive management has been on how it can be used in large environmental projects, individual citizens can be involved in the ongoing pursuit of a sustainable society by participating in small experiments guided by the principles of scientific adaptive management.

## 13.9 Summary

Scientific adaptive management is a process that uses environmental management actions as experiments that simultaneously help solve the problem and reduce the uncertainty of on-going management. This process is not simple trial-and-error but requires an over-arching scheme for dealing with the results of current experiments, unexpected quality changes in the system (i.e.

surprises) and shifts in public opinion. SAM is particularly useful for large environmental projects in which there are mechanisms to effectively control management approaches, but the uncertainty is high and there is no clear alignment between the benefits to individuals and the larger community. Several typical examples of SAM are management of fisheries, forest fire suppression through mosaic of small burns, and dynamic management of water releases in Glenn Canyon. Scientific adaptive management directly addresses human values, uncertainty and control through institutional governance. Even though SAM is usually associated with large environmental projects, the pragmatism and ethical framework is applicable for citizen engagement in sustainability through "massively parallel" small scale and local experiments.


# Chapter 14: Constructing Plausible Scenarios

## 14.1 Introduction

Sometimes when no other approach will lead to real, on-the-ground action, the appropriate course is to explore and compare realistic options. In the case where you have no control, high uncertainty and low public agreement, assembling some creative forecasts is a good start. Scenarios are more than just multiple narratives as described in Chapter 3. Scenarios should also be supported by quantitative analyses, such as simulation models, that provide detail, internal coherence and rigor (Kemp-Benedict ppt). The goal is that well-crafted scenarios can identify some paths worth pursuing and transform the problem into one that can be addressed with scientific adaptive management, environmental entrepreneurism or hedging.

Exploring and employing ambiguity (a major theme of this book) has real value when creating a range of scenarios. It is similar to brainstorming, in which you need to assemble a range of ideas and critiquing suggested ideas too early in the process interferes with the creativity and diversity.

Creating scenarios builds on previous chapters. The assumption sets for many scenario building efforts come from the range of world views (as discussed in Chapter 10: Values and Worldviews). Simulation models are constructed to examine how changes in parameters will lead to different outcomes (as described in Chapter 6: Stock and Flow Systems). These models examine the outcome for particularly selected indicators of progress (as described in Chapter 8: Accounting and Indexes). Finally, politically feasible scenarios are often innovative combinations of familiar components that the public already understands and trusts (as described in Chapter 15: Innovation). This chapter describes two approaches to building and using scenarios; 1) creating a set of scenarios and comparing the assumption sets, and 2) using indicators for specific outcomes to explore how well particular scenarios meet our objectives.

## 14.2 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, the Millennium Ecosystem Assessment Project developed a set of scenarios (Millennium Ecosystem Assessment 2005) that explored potential global futures in the context of four approaches to addressing environmental, social and economic challenges. These were constructed using sets of internally consistent assumptions (worldviews) however the sets contradicted each other. As Raskin (****) states "Global futures cannot be predicted due to three types of indeterminancy-ignorance, surprise and volition." However these scenarios can be used to address this uncertainty and explore novel futures and avoid the "tendency in thinking about the future to simply extrapolate past trends" (Costanza 2000).

Table 14-1: MEA Scenarios (Alcamo ****)

| SCENARIO | A FEW FEATURES |
|---|---|
| Techno-Garden | high performance agriculture<br>innovation and market rewards |

| | |
|---|---|
| Global Orchestration | policy driven<br>effective global governance |
| Adapting Mosaic | regional solutions<br>continued social experimentation |
| Fortress World | wealthy protect their resources<br>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 ****

Considering scenarios 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 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 requires 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. The bind is that we have to confront uncertainty while many people are actively trying to avoid any uncertainty.

## 14.3 Evaluation of scenarios against each other

The utility of creating and comparing scenarios based on world views was presented in Chapter 11. In the situation where the uncertainty about the future is so high that it is pointless to try to evaluate each scenario against the potential threats in the future, the scenarios and their underlying worldviews were used to generate potential threats to challenge the other scenarios. It is called a “utopia” if a predicted future set of conditions leads to a functional worldview, and a “dystopia” if the conditions cause a failure of scenarios derived from that worldview. For a quick review, a scenario based on an egalitarian worldview in which everyone gets along and cooperates will be a “dystopia” in a predicted future in which strong rules are necessary to keep the public in line. A few people might take unfair advantage of the bulk of the population who are cooperating out of their faith in humanity. The three values of building a range of scenarios are that: 1) the assumed public value system is described, 2) a wide range of innovative technology, institution, or management approach can be suggested, and 3) the set of scenarios generates predictions about the future conditions that can be used to test each scenario.

## 14.4 Example of comparison of scenarios

this section will be extracted from a analysis of five scenarios that were derived for the Upper Klamath Lake Basin.

- analysis-of-scenarios-WQW.docx
- technical workshop that examined specific engineering proposals for both hard and green infrastructure
- context presentations represented worldviews, as evidenced from salient concepts or key words
- five scenarios developed and phrased in the positive voice as if from a proponent of that worldview
- important because these lead to particular sets of engineering choices
- these were analyzed to determine the underlying value sets
- sensitivity all scenarios by playing against values and conditions
- highlighted sensitivity to understanding of tenets of democracy, problem facing policy makers in complex problems, and uncertainty

The following scenarios and illustrations depict multiple possible futures for a community on a lakefront.

*** More description will be added here, and in the figure legends ***

Figure 13.1 “Economic Renaissance” – Based on an individualistic view of the environment and economy. Key features are the increase in wealth.

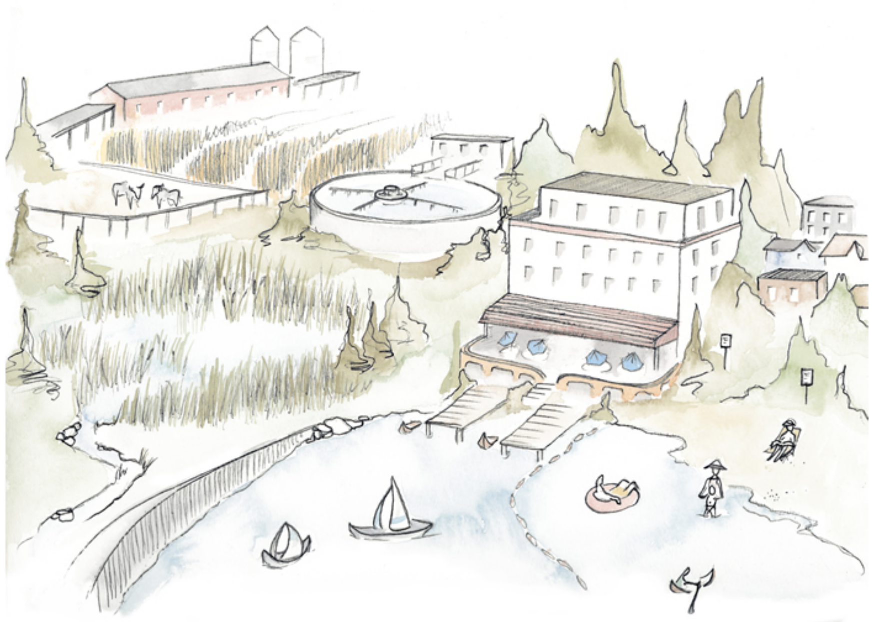


Figure 14-2 “Expert Lake Management” – Based on a hierarchist’s view that with appropriate rules, regulations and technology can create a pristine lake.

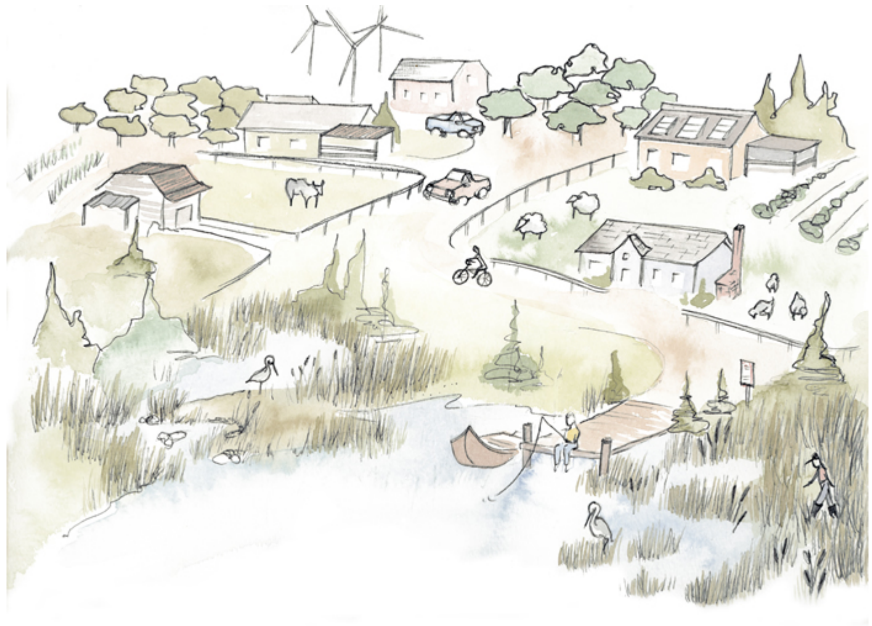


Figure 14-3 “Mosaic” – Based on the egalitarian’s view that we should have smaller, interconnected, and locally governed communities. Notice the absence of large single-crop farms.

Figure 14-4 “Back to Nature” – Based on a deep ecologist’s belief that reducing human impact and take will lead to a more resilient ecosystem/human interaction.

Figure 14-5 “You’re All Crazy” – A blend of fatalistic and technology skeptic views that results in setting up strong barriers to take care of the individual when society and the ecosystems collapse.

## 14.5 Creating indicators for scenarios

A second approach that can be used along with comparing the underlying assumptions of different scenarios is to craft the scenarios so that they can be tested based on environmental, social and economic indicators. As described in Chapter 8, an “indicator” is anything that you might want to see graphed in order to use that data to make a decision. Indicators can be quantitative or qualitative and should be self-explanatory representations of the data. For example a good indicator for the health of a lake might be the number of days that the lake had unhealthy levels of oxygen. It’s obvious that the desired trend in the data is to decrease or eliminate the number of days that the lake suffered from low oxygen stress. It is important to determine if indicators already exist that are used in other models such as global or regional studies. If these aren't usable in their current form, you should at least link to these indicators for comparison. An example of the set of standard indicators is given in Table 18-X.

Table 18-X. Standard indicators of goals as suggested by Raskin ****. These are derived from available demographic, social, environmental and economic data.

| General Goals with Indicators | Units |
|---|---|
| Peace | >1000 deaths per year |
| Freedom | Gender equity |
| Development | Number of hungry people |
| Climate change | Atmospheric CO2 concentration |
| Ecosystems | Forest area in millions of hectares |
| Water stress | Billions of people without drinking water |
| Population | Billions of people |
| Economy | GDP |
| International equity | Poor/rich income ratio |

Smaller or more targeted uses of scenarios would require more specialized and narrow data. The Genuine Progress Index as used by states such as Maryland and Utah provide and example of this specificity (see http://www.green.maryland.gov/mdgpi/index.asp).

Maryland uses 26 indicators in three broad categories: economic, environmental and social well being. The economic indicators include personal consumption, income equality and five others. The environmental indicators include the cost of water pollution, cost of air pollution, wetland change and six others. The social inicators include the value of higher education, the cost of crime, the value of volunteerism and seven others. Each of these indicators relies on multiple data sources. For example the cost of water pollution compiles costs and benefits from recreation, industrial use, and costs due to loss of use such as from forgone recreation revenue. There is significant effort required to compile the data, verify and keep these indicators up to date.

The reliance on indicators also requires that there is an underlying simulation model that can simulate the future outcomes for different selections of parameters or policy choices. These simulation models are very similar to the systems models that we used in Chapter 6 (in fact, Maryland uses the same STELLA simulation program that we used). The Maryland Genuine Progress simulation helps citizens explore the benefits of investing in green technology and how it would affect their state's economy, employment and other factors.

Building what is called a "narrative led, indicator driven scenario" is a substantial project. Kemp-Benedict (2006) states "Projects must be carried out using inexpensive tools under tight budgets with incomplete data sets and incomplete data." The three major criteria for these scenarios is that they play a supporting role in decision making, produce outputs that are meaningful and useful to external audiences, and feature some sort of illustration or visualization of the outcomes. Three pieces of major effort in these projects are: 1) to collect input on the narratives from experts and stakeholders, 2) organize the modeling effort and get continual feedback from experts and stakeholders, and 3) to create interim and final products that are suitable for a wide audience (Kemp-Benedict 2006). As we saw in the chapter on networks (pg ***) and the discussion of exploratory data analysis (pg ***), graphic visualization and interactive databases are extremely useful in connecting many people with a wide range of backgrounds to the complex issues that are involved in solving environmental problems.

## 14.6 Implementation of lessons from scenarios

Although it is useful to have global scenarios that deal with the big problems on Earth, scenarios can be very effective tool in pushing forward on otherwise ill-defined problems. There are several important characteristics of more actionable scenarios. First, the scale of the problem must be defined and severely restricted to some zone in which action could be possible. For example, a set of scenarios that describe how a city can be an economic hub for the restoration of a lake may provide concrete suggestions for actions that local industries, citizens, and agencies can take. In contrast describing how climate change may change global weather patterns provides very few direct actions that anyone can take. This advantage of smaller scale projects is particularly important when describing many small experiments that could be carried out simultaneously to address the uncertainty (De Young and Princen 2012). Second, the scenarios should be built from components that are familiar. The importance of familiarity is not to stress the *status quo* but to provide the participants a larger degree of acceptance and trust in the process. It is human nature to feel more comfortable with the familiar and distrust the novel. Making sure that the future looks like it is continuous with the present, just a different mixture of components, is important for the broad participation that is necessary. Finally, considering environmental scenarios needs to pay particular attention to the "green quandary" in which you need to have sustainable actions taken right away but you also need to depend the slow and tedious process deliberative democracy. There is really no choice in this divide between rapid solutions and a democratic process that is connected to authentic ecological feedbacks; pluralistic democracy is required for sustainability.

## 14.7 Summary

Scenarios are a powerful and sophisticated approach to move ahead on environmental problems that otherwise might be stalled due to a lack of public agreement, high uncertainty, and low ability to control the outcome at this point. Based on sets of assumptions that are inherent in worldviews, basic scenarios can be constructed and tested against each other. The potential futures of the Klamath Basin following lake restoration is provided as an example of how different worldviews can be compared objectively. Identifying particular indicators and combining them into a simulation model can support a more sophisticated decision process. Maryland's Genuine Progress Indicators are given as an example of using targeted indicators and publically available simulations. The goal of simulations is to describe plausible futures and deals with uncertainty in a manner that supports democratic public involvement and creates a shared vision for a desirable society.


# Chapter 15: Diversification and Multi-Criteria Approaches

## 15.1 Introduction

There are three categories of problem types that rely mostly on management approaches. These are: 1) simple problems that probably have multiple potential benefits, 2) low-control/high-uncertainty situations for which a portfolio of approaches must be selected and managed, and 3) the all too common situation in which there is good information and good control but public divisiveness must be managed for either side to make progress. These approaches are more about managing the situation than finding new solutions or dealing with uncertainty.

## 15.2 Project management for multiple outcomes

Even in what we are calling a "simple" problem situation, there are many factors that must be considered. One of the reasons that some problems become classified as "simple" is that there is agreement of all the stakeholders that something must be done. Often this is not because they agree on what exactly must be done or that all the stakeholders will benefit in the same way from the outcomes. The challenge is to create a process that is transparent, that is meaningful for the participants and that provides a range of benefits.

An example of this sort of situation might be if a ***

Process (see BSC)

Set overall goals – get buy in

Get specific objectives (tasks) and budget

Identify aspects of the management

Capital sources

Operational

Stakeholder outcomes

Create initiatives that are coherent and manageable

Set up indexes that can be tracked for progress

## 15.3 Hedging with a portfolio of approaches

risk management

identify risk factors, minimize through combination of smaller approaches that

key problem is to identify which risks are independent and which are related – the statistics are very different

## 15.4 Multi-criteria method when public is polarized

Multiattribute utility measurements – This approach, described by Gardiner and Edwards (1975), is a method to account for a range of utilities for a group of citizens and then help make a decision. It is a combination accounting and decision processes. The method starts by cataloging all the individual benefits of a particular project and then use a ten-step method to replace contentious “folk-ways” that people fall into when trying to protect their own interests and instead focus on the areas of agreement that are broadly beneficial.

Link to reference-notes/gardiner-edwards-1975.html

## 15.5 Summary


# Chapter 16: Innovation by design

## 16.1 Introduction

The world is complex and may be getting more complex because of human society employing increasing amounts of power to manage and control the environment. As the diversity of these problems expands, we will need to use new approaches to solve them. Innovation brings together new technical and social ingenuity to address problems in novel ways. Our environmental situation is changing substantially and so must the approaches that we use to diagnose and solve these problems. In addition, human control over the environment has accelerated the pace of change and this will require a level of innovation just to maintain a healthy environment.

The complexity of environmental problems has six major features (Homer-Dixon ****, pg 104). 1) There are multiple interacting components that are involved in any problem. 2) The causal connections are dense which results from them being tied to human actions on some way. 3) All of the problems are interdependent. There are no single solutions to single problems anymore. Everything is connected. 4) Complex problems exhibit synergy that can be good if we are on the path to solving them, but it can be worse if the situation is deteriorating. These problems are often called "vicious spiral" because as deterioration happens the rate is accelerating and the scope is broadening. 5) These problems exist because the environment is an open system and all of our actions *** check this ***. 6) Many of the problems we face have thresholds and exhibit non-linear or catastrophic behavior. As we near these thresholds we may risk huge negative effects even for the same incremental new damage that the system had absorbed in the past. Worst of all, these thresholds are mostly shrouded in uncertainty and we may not realize we have crossed the threshold until too late. These complex problems pose new challenges to our society and will require new, innovative technology, methods and institutions to deal with them. The key question facing us is whether our educational, science and political systems will be able to provide the required amount and quality of innovation to solve these problems, or will we continue to widen what Homer-Dixon calls the “ingenuity gap,” where we create new problems faster than we attend to solving them?

## 16.2 Old problems in new contexts

Some of our current problems have been around for a long time but are now taking on new dimensions. For example, 40% of the people use firewood or charcoal for cooking and for about half of these people, wood is their primary energy source. In addition, 1.2 billion people lack access to clean drinking water. Compounding this, 40% of all protein consumed by humans requires synthetic fertilizer (Smil ****). With the expanding global population, these problems are all coming together. Fuel wood sources are being depleted at the same time that people are converting forests to farmland. Runoff from agriculture and industries is polluting water sources for both rural and urban poor. The costs of energy are driving up the costs of fertilizer and, in turn, the costs of food. New technologies, local institutions that control the use of these technologies for social benefits, and methods to disseminate both technology and institutions around the globe are needed.

Treadle powered water pumps are a case study in innovation to serve the public good.

- Insert example
- References Elkington and Hartigan 2008, Polak 2008
- Pump design
- Use by farmers to increase production
- Make profit which pays for the pump
- Develops ownership and markets

- Picture of a treadle pump
- Summary of social enterprise/innovation

## 16.3 Combinatorial Innovation

Although it is common to use the word “innovation” to mean or imply something totally new, the most common and powerful form of innovation is to combine tested components into new configurations for new uses. This process defines a problem and then searches for potential solutions by piecing together and connecting parts. A simple example is the creation of solar-powered community water in rural areas of Nicaragua. This required both technical and social components that worked together to address the entire problem and provide substantial value to the community. In the case that I was involved in (and there are many other examples), this included at least the following components:

- Drilling a well
- Creating a storage system and distribution pipes to homes
- Installation of a solar array to power the pump
- Creation of community organization that could handle the billing for installation and continued maintenance
- Establishing local technicians to monitor and service the solar panels, pumps, pipes and storage tank
- Involvement of public health professionals to change health habits

The completed project had community support, community financial backing, and local experts. In addition there were a range of benefits to families that could be developed, such as the ability to wash food, sustain personal hygiene (including brushing teeth), and maintain kitchen cleanliness, all of which were not possible when they were drawing water from a semi-polluted stream.
The community water project also served as a platform for several other related projects. These projects would not have been

successful if an outside agency had simply piped in potable water to the houses. For example, several homes explored the use of the grey water from their tap to create patio gardens. These gardens were used to raise fruits and vegetables that were needed in their personal diets. A beneficial side effect was for these families to put fences around their houses to keep the pigs, cows, goats and chickens away from the patio garden, which improved the quality of the family's health. Some farmers explored the use of drip irrigation by essentially using some of the same components (at a smaller, cheaper scale) to provide seasonal drip irrigation of vegetables and fruits that they could eat or even take to the local market. A storefront was set up in a local town to sell solar panels and ancillary equipment using a revolving micro-credit scheme. Thus, a whole host of projects grew out of an initial innovative combination of solar power and community organization. The green technology and the institutional development together made this possible and lead to the diverse benefits for the community.

Figure 16-1 A happy group of community members and capstone students celebrate the final attachment of the water reservoir to the solar drip-irrigation project.

## 16.4 Nurturing and supporting innovation

It has been said that "invention is a flower, innovation is a weed" (Metcalfe 1999). By this he means that a flower garden takes continual tending and is delicate, but innovations should be able to spread on their own given the right conditions. If innovations are crucial to continued progress with environmental problems, as I claim, then how can we promote socially beneficial innovations that have all the necessary attributes to spread on their own? There are three aspects to this support: identifying the gap between what we need to solve and what we actually can solve, modeling problems to create new insights, and creating synergistic institutions.

We have to recognize that there is a gap between the problems that we are creating and our ability to solve these with current technology and social institutions. Part of the reason for this gap is our over-confidence in technology as a panacea for all problems. Another aspect of this gap is that we have a poor understanding of, and in fact a general social aversion to, uncertainty. When we add a new chemical to the catalog, create a novel plant of bacteria strain, or construct a new dam, we are actually creating uncertainty. If it takes a few good inventors to come up with a totally new compound, as it did to invent CFCs, it may take thousands of research scientists, government employees and policy analysts to come up with a way to reduce the CFCs in the environment after only a couple decades of use. In the case of CFCs the uncertainty multiplier was enormous because of its rapid adoption, global use and remoteness of the immediate cause (catalysis of ozone destruction). The unintended consequences of CFC invention were astounding. But there are many other inventions or novel actions that had unintended consequences. Tenner describes several of these in detail in his book entitled “Why things bite back: technology and the revenge of unintended consequences”. *** final sentence on the gap ***

In order to encourage innovation, the exploration of environmental problems has to take a more empirical approach, relying on actual observations, data and evidence. Starting with theory and generalizations is more likely to result in general solutions that are not place and issue specific enough. Remember Wendell Berry’s exhortation to “solve in the pattern” (Berry 1972). New approaches to data analysis (Andrienko and Andrienko 2006) provide the background and tools to explore large environmental data sets, look for possible connections in a rigorous manner, and develop new types of hypotheses for testing. Many of these methods depend on using software to create visual representations that serve to stimulate discussion and lead to a more insightful treatment of the problem. Figure 15-2 gives an example of the type of visualization tool that can be used to explore observations and formulate working hypotheses.

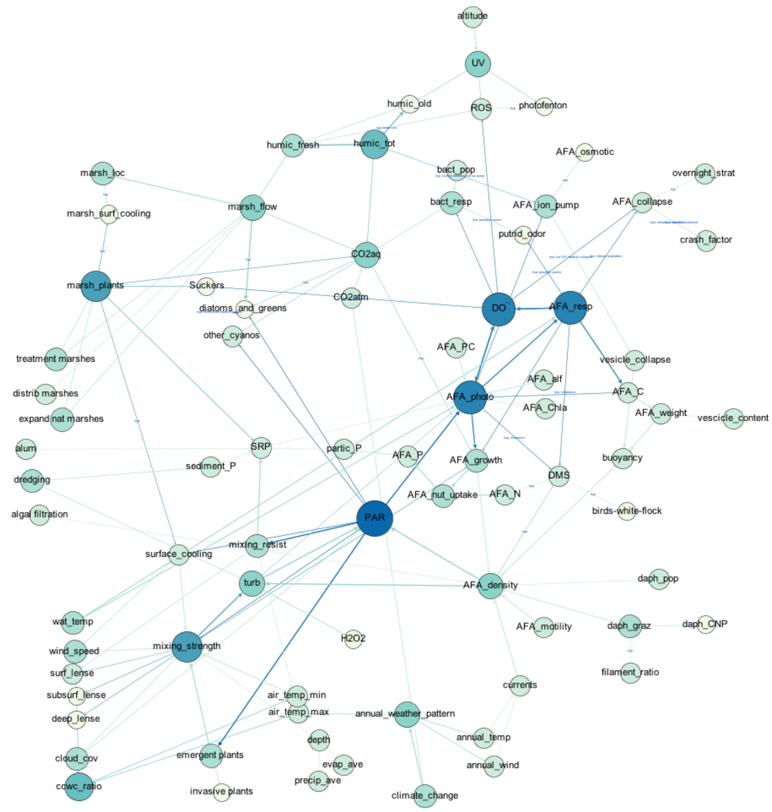



Figure 16-2 Network "graph" of possible interactions that could lead to toxic algal blooms in Upper Klamath Lake, Oregon. All linkages can be documented and described as observed or hypothetical. The graph itself can be modified on the fly as a group of lake researchers might add new connections or insight.

Why we need institutional or cultural support - reason 1: rapid change from cultural evolution--- Every innovation needs to be wrapped in a social understanding of how and when it will be used, i.e. an institutional framework.

Homer-Dixon 194 - "the greater complexity of our world requires greater complexity in our technologies and institutions" <!-- which is applying Ashby's Law of requisite complexity to the solution of these problems -->

*** more here from Homer-Dixon

Homer-Dixon – 205 cultural evolution is rapid enough and refering to Peter Richerson's work - "culture is "information -- skills, attitudes, beliefs, values -- capable of affecting individuals' behavior, which they acquire from others by teaching, imitation, and other forms of social learning."

225 - Solow's study capital only explained 12.5 to 20% of improvements in labor output, the rest was called the "residual" and came from better methods, not more machines

reason 2: need to have growth and innovation under our social control *** important not to launch innovations on their own – as described by Norgaard 1994– positivism leads to too much confidence in progress, - need co-evolving ecological and socials systems that are more pluralistic,

Adams – indeterminancy,

Vitek and Jackson 2008 – take an approach that acknowledges our ignorance

Schwartz - Practical wisdom, i.e. cultural context, provides situational context for making decisions about new ideas that strict rules can’t keep up with

*final sentence* – Understanding and dealing with the uncertainty and indeterminancy of novel approaches requires a strong social construction ….

## 16.5 Examples of innovative solutions to environmental problems

several examples with technology components being combined and social and institutional support

1. water purification in Kenya – (Evan Thomas) -
    - SWEET lab – develops sensors
    - See pdf-articles/SWEET…

2. smart grid in Salem (Hughes)– with substantial social component
    - List of technologies
    - Cooperating businesses
    - Role of the home – power use, power generation, power storage

3. localization of agriculture De Young and Princen 2012
    - How to prepare for the downshift in energy and materials
    - Not all new components – many familiar and tested from previous generations
    - Many small experiments with everybody involved – all of us
    - Information availability and how it is used is the main piece of how this is different than 4000 years ago, including technology that helps share this information (examples urban orchards, hyperlocal food purchasing apps for your neighborhood, on-line CSAs)
    - The process is innovative – support for these experiments

- Requires a shift in dominant worldview away from competitor-winner/looser society toward a partnership society

## 16.6 Summary

There is an ingenuity gap – need innovation and institutional ***

We even need innovation to address older problems that are morphing into complex and wicked problems as we have population growth

Many, if not most, innovations are the result of combining tested parts into a new solution. These parts include technology, institutions,

Innovation requires nurturing and on-going support,

Examples demonstrate combining technology, social, economic components


# Chapter 17: Environmental Entrepreneurism

## 17.1 Introduction

A simple starting definition for environmental entrepreneurism (Env-Ent) is that it is an activity that seeks to correct failures of environmental regulation, social and market mechanisms to establish good stewardship and uses business approaches to construct solutions. The two complementary foci for environmental entrepreneurism are to either use market driven forces to correct problems or to construct the conditions that allow market driven forces to work. Those conditions probably include a mix of profit opportunities, subsidies and incentives, regulations, and public support. Environmental entrepreneurism embraces the uncertainty, asymmetry of knowledge, and public value diversity (as we shall explore in this chapter), it is a good approach to problems that have high uncertainty, no particular coherent framework for individual and public values, but in which there is some expectation of controllability (even if only at a small scale).

There are many agricultural, rural areas in developing countries in which water available for irrigation is limited by pumping infrastructure. If farmers were able to pump water just a few hundred meters, they would be able to: irrigate crops, obtain higher yields, earn extra money, and reinvest some of that in their enterprise. Paul Pollack visited rural poor around the world and, after listening to their stories, decided that it was simple, the these people are poor because they don’t make enough money. He also gathered that a simple, human powered pump could really help them. He and others designed a treadle pump that one person could use to pump water from shallow wells and irrigate crops. These pumps only cost *** and could be easily maintained and repaired. There are even versions of these pumps that are designed around childrens' teeter-totters that keep kids busy while pumping water. These pumps weren't given away for free. The farmers had to work to pay off the loan. This example illustrates some of the key aspects of environmental entrepreneurism: scale, design, market and a mechanism to create value.

<insert image of treadle pump>

This book will not focus on making money off environmental opportunities, such as proposed by Anderson and Leal (1997). There are certainly some golden opportunities to make a killing off of incentives or subsidies. The carbon market is a good example of a situation in which a lot of money could be made if the original auction is done improperly or if there are loopholes. There is no way to eliminate such adventitious profit taking but hopefully this will not undermine the substantial benefits from environmental entrepreneurial driven by the desire to improve the human condition.

## 17.2 Environmental entrepreneurism is well suited to certain problems

The summary of problem types, dimensions of the problems and approaches presented in Table 13.3 indicates that problems that are characterized by high uncertainty, good controllability, and low value coherence should be candidates for the Env-Ent approach. This can be explained from the theory of social and entrepreneurism and align with the three dimensions of uncertainty, control and values.

*Entrepreneurism embraces uncertainty*. According to York and Vankataraman (2010) environmental entrepreneurs address uncertainty, provide innovations and locate resources.. In fact, they are driven by the opportunities that are created in the situations of uncertainty, knowledge asymmetry and ambiguity.

*Environmental Entrepreneurs help create institutions to control the situation*. Environmental entrepreneurs play a more proactive role in creating institutions to meet their needs than incumbent firms (Dean and McMullen 2007). By doing this they help internalize the externalities rather than only seeking a political or imposed regulatory solution. However, regulations can be a necessary adjunct. For when there is a failure of the market to control excess phosphorus use in a watershed (that leads to the degradation of the lake water quality), regulations that reduce the import of phosphorus fertilizer into a lake basin can make other methods of lawn and plant care more competitive without the damage to the lake ecosystem (Lake Oswego study ****). Entrepreneurs also will use some forms of regulation to establish a property right in a public setting. For example, allowing only a certain number of anchoring permits for fishing boats allows the fleet size and fishing effort to be controlled.

*Environmental entrepreneurs deal with value conflict.* They are better at dealing with multiple value systems than incumbent firms (York and Vankataraman 2010). In many of these cases, there is a low value coherence because there is no current agreement, and no mechanism to reach and agreement, on how to value those resources. Resource allocation requires political and economic freedom, eco-augmenting systems need to be at a delicate balance between regulation and freedom. Strict valuation of resources restricts experimentation. There needs to be the ability/freedom to make mistakes and learn from them (which is missing in most government agencies).

Thus in problems that have high uncertainty, possible control and values mismatch, and environmental entrepreneurism approach can provide three advantages. First, there doesn't have to be a tradeoff between the environment and the economy. Env-Ent solutions often provide ways to improve the environment while creating local employment in good jobs. For example, replacing outdated infrastructure of sewage and runoff treatment with green infrastructure such as riparian restoration and bioswales creates jobs dealing with plants and wetlands. Second, env-entrep should reduce transaction costs. For example the TMDL model and enforcement is very expensive. Independent verification (through lab tests) of the amount of P actually removed in plant batches would be much more certain and free to the government. Third, Env-Ent is more likely to introduce both technical and social innovations than incumbent firms (York and Venkataraman 2010). The more uncertain and intractable the problem is then the better Env-Entrep are able to handle the problem relative to incumbent firms.

The very bottom-nature of this mode of engagement poses one of the biggest challenges for relying on Env-Ent. It is unclear what conditions are necessary to establish an environment that would let this approach start up and thrive. An additional worry for environmental managers in government is that once environmental entrepreneurism "kicks in" how is it controlled and how can the results be evaluated compared to current environmental practice. The issues of control and evaluation are dealt with at the end of this chapter and the final chapter of the book.

## 17.3 Innovation is often a key part of entrepreneurism

We often associate innovation with break-through technological advances that open up whole new areas in science and business. But innovations can be social, technical, market, informational, institutional or any combination of all of these. There are many innovations that use tested components and in new ways and new combinations.

Entrepreneurism often relies on novel combinations of available technologies, organizational structure, and business practices to solve problems. There doesn't have to be a "killer app" or a totally wild idea to be work. Bringing together off-the-shelf technologies (including institutional and market approaches as types of technologies) into new situations can add enough value to participants to drive the process.

Rural electrification in Nicaragua is a good example. A renewable energy and social justice NGO, Green Empowerment, combined solar water pumping, community organization, public health, drip irrigation, information resources, and small business practices to provide water to a rural farming community in Nicaragua.

****Insert Details*

****Pictures

****Outcomes – Cuenca Clima

## 17.4 Importance of scale

Because Env-Ent relies on business platform and financial transactions, there has to be a strong degree of control. People who do work need to be paid, equipment and supplies need to be paid for, and investments have to provide a financial return on investment. If there isn't enough control to expect that these transactions be completed, then these efforts are donations. This is not to deny that there is a role for philanthropy in many environmental problems, but environmental entrepreneurism is not philanthropy.

Small projects allow for the degree of control that is necessary. This could mean that the overall scale or the projects are small or that there are large projects that can be broken down into manageable small-scale components. A large project with a bunch of small components may have too high an overhead, management cost for other forms of environmental management. One of big promises for env-ent is that it can address broad problems that are slightly different in every particular instance. Unleashing the power and innovation of market forces on environmental problems could bring widespread improvements to many areas of the Earth that are currently underserved.

## 17.5 Entrepreneurial projects require a different type of control

Entrepreneurial approaches are often a collection of interaction components, i.e. complex systems. These are not easily controlled in the same way as hierarchical organizations, such as businesses or governments might be. The control is embedded in the system itself and the structure of the control is similar to the structure of the system being controlled. This follows Ashby's Law of Requisite Complexity, the control has to have the same degree of complexity as the system. A simple way to envision this is that the control is from the middle rather than top down, like businesses, or bottom up, like democracies.

Control of complex systems is apt to have multiple layers connected through several key points. The challenge is to identify the key connectors and work on these. That is the idea behind ecological tipping points. Managing a few central and key components of the ecosystem will allow improvements in ecosystem function that spread down to the individual species and micro-habitat level and up to the overall ecosystem. A good example of managing the tipping point is described by *** in his description of *** Island. The fishing industry was using dynamite in order to get reef fish. This caused damage to many other parts of the reef and was extremely dangerous to humans. By limiting the access to underwater fuses and by providing incentives to create buffer zones (marine management areas), environmentalists*** a conservation organization was able to re-establish a health fishery and improve human well-being.

Because the environmental entrepreneurism is similar to other complex systems, it is useful to describe the general principles for controlling complex systems. There are four guidelines for controlling, complex systems including trying to manage environmental entrepreneurism:

1. Don't use overwhelming power. That only turns the system into some other type of problem.
2. You need to promote conditions that allow native agents (people, animals, plants) to pursue their own livelihood.
3. Problems must be addressed simultaneously at multiple scales.
4. There has to be a continued investment and commitment to the protecting and increasing the inherent diversity. The reason that most complex approaches work is that they take advantage of this diversity and it is not sustainable to be eliminated it in the first round of "solutions".

The demographic transition provides a good example of how entrepreneurial approaches can be useful. Western Europe went through a simultaneous industrialization and a shift from high birth and death rates to low birth and death rates. This phenomenon is described as the classical demographic transition. Such a transition is extremely interesting a potential pattern for less developed countries to increase economic wealth, stabilize population growth and have healthier people. Studies of the control of this type of transition in developing countries show that it is not the macro-economic indicators that are relevant but the small levers at the scale of communities. Effective strategies entail education for women and girls, microfinance loans, commitment to human rights, and empowering local institutions to be involved in decision making.

****Insert example: Wangari Maathai and the Kenyan Green Belt Movement*

*activities*

*results*

***Sidebar: 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. These species doesn't necessarily control the most energy flow or have the highest abundance. 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 amplify the role of the keystone species beyond just the one-dimensional impact on gross energy or material flows. We need to understand how changing the conditions at a small scale, by individual or small interest group activities, could shape the outcome of landscape and society-wide scale process and then look for those opportunities.

## 17.6 Business platforms

Environmental Entrepreneurism is based on essentially the same platform as all business aims for a different mix of social, environmental and financial outcomes. This means that an env-ent venture needs to be planned, initiated and managed in an effective manner. There are extensive knowledge and skills that are needed to be successful. Running a business that must provide both a reasonable return to the investors and contribute social and environmental benefits is even more challenging than a strict for-profit business. The additional constraints limit some strategies and may detract from competitiveness.

The purpose of this chapter is to describe how environmental entrepreneurism works, not to instruct you on how to be an environmental entrepreneur. For background on the world of running an environmental or social entrepreneurial business, please see **

** add in references on social entrepreneurship

The point is to let the business aspect make the enterprise be sustainable, i.e. to persist and thrive without continued subsidies.

Give aways don’t work (Fisher in Innovations)

Good business management principles include

Novy-Hildesley 2009– critique of KickStart and how to fund inventions

There is a range of social and entrepreneurism businesses that are blend of profit and social benefit. Alter (*** ref), Boyd (pg 8 www.virtueventures.com), Elkington and Hartigan (****) and Nichols (pg 209) have described categories that essentially range from pure for-profit to pure not-for-profit organizations. Alter's model for the spectrum of these identifies the role of income generation vs. social responsibility. Linnanen's typology focuses on the goals of the entrepreneur and whether they want to change the world or make money.

Table 17-1 Alter's hybrid spectrum model (Boyd et al. 2009).

- Traditional non-profit
- Non-profit with income generation activities
- Social Enterprise
- Socially responsible business
- Corporation practicing social responsibility
- Traditional for-profit

Table 17-2 Linnanen's typology of entrepreneur.

| | | Desire to change the world | |
|---|---|---|---|
| | | High | Low |
| Desire to make | High | successful idealist, positive feedback from stakeholders allows increase in growth to | opportunist, usually involved in |

| | | | |
|---|---|---|---|
| money | | push world changing to push market and back to stakeholders | environmental technology and no change in the entrepreneur's values |
| | Low | non-profit, such as a sustainability think-tank | self-employer, such as small business that lives off low resource use |

Most of the environmental entrepreneurial businesses will be in the middle of the spectrum, using a combination of income generation and environmental responsibility. The following three examples demonstrate some of the features of these hybrid enterprises and the tradeoffs that they have made.

**** Expand and get pictures for each – I've already used the treadle pump example, maybe find another one*

Sun Ovens (Boyd et al 2009) – high quality solar ovens for poor around the world, reduce biomass fuel depletion which leads to environmental degradation, business model in developing countries is much different that in the US and requires more steps to get into the market, work with agencies and NGOs for example to get stoves into refuge camps, competition for lower quality but much cheaper ($15 vs $150) ovens is hurting them

Guayaki (Boyd et al 2009) is a yerba mate (organic drink) made from organic products from SA rainforests. Developed direct relationship to farmers and guaranteed a price for their product, even if it wasn't up to their specifications yet. Process of growing and harvesting can be done while saving the rainforest. Competition from organic tea companies with established distribution.

Treadle pumps (Polak 2007) – foot treadle pumps that can be used to irrigate small (1 acre: .5 ha) farms. Create food and income from market produce. Develop farmers links to the local markets and understanding of what produce and when. New types of agriculture (compared to agri-business large farms) with different market, risk profile, and balance of food vs. income production for the farmer.

## 17.7 Summary

Environmental entrepreneurism is a challenging mode of engaging with problems that have a particular mix of control, values and uncertainty. This approach is challenging because it requires an organization to simultaneously meet business objectives (i.e. profit) and provide environmental benefits. However, this mode could is one of the most promising ways to address distributed and diverse problems. Thus environmental entrepreneurial enterprises are usually small and distributed themselves. This complexity requires a different mode of control. Env-ent approaches are more likely to be nurtured and launched than explicitly controlled to meet specific objectives. This means that establishing the conditions for env-ent to take hold is crucial for environmental managers. Government agencies or large organizations have to work to set the right mix of incentives and proscriptions that allow individuals and small businesses to flourish. Most of the examples of environmental entrepreneurial businesses are a hybrid that use some related activity to generate profit. The mission of these businesses is not philanthropic, but rather to create a self-sustaining enterprise that will serve the publics interests through employment and environmental improvement.


# Chapter 18: Reflexive Evaluation

Making progress with a transdisciplinary science framework

## 18.1 Introduction

This text has described a method for addressing environmental problems that brings in complexity, uncertainty, and values. This is necessary because most of the problems that we are dealing with as a society are “wicked”. These problems contain uncertainty and non-coherent values between individuals and the community, which are simultaneously interacting and. A key characteristic of “wicked” problems is that they are never solved; there is no stopping rule that tells us we are done. Wicked problem example 1. Wicked problem example 2. Thus, from the beginning, we should not expect clear outcomes that signal success and completion. Instead we must rely on a constant process of evaluation and iteration. There may be pieces of the projects that can be addressed with traditional scientific hypothesis testing, but for the larger flow of the projects we will have to rely on a more reflective epistemology. We have to learn from our efforts and make adjustments while we continue to work on the problem.

## 18.2 Defining a scientific evaluation process

The evaluation of our attempts and progress will be scientific in that it is systematic, rigorous and verifiable. We need to use a restricted definition of science that does not assume everyone involved agrees on what a “fact” is or how to verify if a fact is true. Outside bench science, and in any enterprise that includes the public, the assumption that there is a single method to verify what a fact is just doesn’t hold. Our modified definition of science also needs to avoid the implication that the use of technology is required or any biases that science will lead to progress. Instead we can define science as:

> Science is a rigorous, systematic and iterative activity that builds knowledge through seeking empirical evidence and making testable predictions followed by evaluation and revision. The activity should build knowledge that can be reliably used by others.

This definition can be applied to assessing activities that are creating new types of knowledge. A key characteristic of this knowledge is that it is created and shared by scientists, professionals and the public. We will also be able to use this definition of science to describe quality and measures of success that will lead to identifying good practices.

It is important that values are considered as part of the evaluation. We can stay within objective, fact-driven, decision processes by creating objective statements about values. For example, “stakeholder group X values biodiversity more than it values an efficient and large water treatment plant” can be treated as a fact and can be verified with members of stakeholder group X. This is a statement about values, not a value judgment on the part of the observer. Extending this to include the judgment or members in stakeholder group X, you might state that they favor biodiversity more than a sewage treatment plant “because they feel there is ample evidence that the threatened biodiversity loss can’t be replaced, and they don’t want to make the trade-off to lose any species to this proposed project”. Again, the judgment criteria are described as they hold for this group. Thus observers and coordinators can make objective statements about values, but for stakeholders to be involved each stakeholder has to make their own value statements.

In order for stakeholders and participants to inject their values into scientific judgments, they must make statements that are based on evidence for the problem at hand and are not allowed to introduce non-negotiable demands, or pre-experiential beliefs of dogma. For example an involved citizen might make a statement such as "Based on the evidence that I've seen and my analysis, I believe that we should create a reserve for endangered White-Tailed Deer." It would not be useful in this scientific evaluation process for them to say "I consider preserving these deer to be a sacred trust and I cannot discuss any project that would compromise their chances of survival to any extent." The first statement is what we referred to in Chapter 19: Scientific Adaptive Management as a "considered value", i.e. the person is basing the value on evidence pertinent to this particular decision and willing to consider changing their belief if different evidence were made available or if they were presented with a different analysis of the problem. The second example is what we called a "held value", in which the holder of this value will not consider any other information. Strongly held values are important for civilization and are handled by social and political mechanisms. Scientific evaluation cannot reconcile conflicts that arise between these beliefs and must limit its focus to the region of facts and considered values. One of the powerful aspects of scientific evaluation comes from drawing the line between considered and held values; doing so centers the discussion in a situation where everything (including values and beliefs) must be based on pertinent evidence. A "litmus" test for stakeholders is that they should be able to describe evidence or analysis that would make them revise their beliefs. Applying these criteria for evidence at the beginning of a decision process should improve the flow of the deliberation and allow that process to be rigorous and systematic without discarding important information about how participants' values and beliefs.

## 18.3 Evaluation of personal progress

Thoughtful and deliberate citizens should always be evaluating if their effort to learn about a problem has been valuable; i.e. to ask the question, "Has my effort been worth it?" Answering this question should involve examining the progress made but also assessing whether you think you're on the right path. Will this approach to learning and acting on an environmental problem meet your goals? At some level this is second nature to all of us, but the intentional self-evaluation should include more than an itemization of the specific tasks completed. Based on what you have learned so far in addressing the problem, you need to ask yourself if the goals that you set are still appropriate. It may be your engagement with the problem has changed your understanding or values and you need to restate your goals. For example, you may have been working on cleaning up a streambed with the goal of creating an attractive natural area, but in doing so you realized that removal of some barriers downstream would make this whole area accessible to native fish. In this case, the engagement refined your goals to focus on a stricter definition of what a natural area should entail. Or you might have been cleaning up a streambed only to realize that the sources of pollution and litter upstream were un-controlled. You might shift your focus to addressing that problem or, if you believe it is an insurmountable problem, you might pick another stream to volunteer on. A very challenging re-evaluation and re-adjustment involves considering the level of uncertainty and complexity of the problem as you first imagined it and how that might have changed with your increased knowledge. As you learn more about any wicked problem and become personally involved, your level of uncertainty is bound to go up and even call into question your personal values and beliefs. You should not dismiss this because this level of re-evaluation is the most valuable form of learning; however, you do have to take the longer view, as described elsewhere in this text, one that embraces the uncertainty that will eventually be valuable.

On a procedural level, an evaluation of your personal involvement in a problem should examine which approaches and tools you have brought to bear and their effectiveness. You should look at the discovery and diagnostic tools that were employed and how much effort was assigned to each (informally or deliberately). This should lead to re-allocating effort between approaches or adding additional approaches that now seem potentially effective.

The personal reflection described above is scientific because it is systematic, rigorous, iterative, and includes values. It is systematic because one must evaluate all of the inputs and efforts in order to gain new knowledge. The rigor comes from testing each portion of new understanding down to the level of questioning original assumptions to see if they still hold, and, in the event that they do not, creating new goals. This evaluation needs to take place concurrently with approaches to solving the problem so that adjustments can be made or a whole a new set of objectives can be iterated if necessary. Finally, personal values are stated with respect to whether progress is made toward intended goals and whether or not efforts have been worth it. The ability to evaluate your own progress without becoming paralyzed by the uncertainty of whether you are doing the right thing is learned through experience and perseverance.

## 18.4 Multiple-participant project evaluation.

The evaluation of projects uses the same basic template as self-evaluation. The process includes examining progress on tasks and objectives, re-evaluating goals, assessing the value of the knowledge gained and coming to grips with the uncertainty that has been created through the creation of new knowledge.

One major difference for evaluating environmental projects is that the problems are situated in authentic communities that have varied social, economic and scientific issues. For example, addressing the progress on establishing fishing quotas and a marine reserve would have to start by acknowledging where the community was socially, economically and environmentally at the beginning of the project and working from there. This can be challenging because participants may have very different and conflicting descriptions of the previous state of the resource. The evaluation process will be different than a strictly technical project

*** in five key ways. First, the project should be creating more knowledge and this knowledge should include new types of information that might not have been predicted at the start. Thus the evaluation of a possibly successful project has to expand its original definition of knowledge. Second, the evaluation needs to be contextualized in the community, not in the participating academic disciplines. This includes using everyday language as the dominant form of communication and avoiding silos of expertise within the project. Third, different participants may have different and non-converging definitions of success. The goal of the evaluation should be to accurately state the range of definitions, not to force convergence. Fourth, the ultimate solution may require a paradigmatic shift in the community. This means that the evaluation would document the discontinuity from one way of doing business to another disconnected method. Such paradigmatic shifts are often un-predictable and can’t be described in terms of cause and effect. In essence, the shift in paradigm may be supported by many contributing factors but no one set would force the change. This fourth condition is very similar to the fifth, which is that the path to success may not be deterministic but may rely on some emergent behavior of the system. For example, a public campaign to clean up a stream may drag along for quite awhile until a critical threshold of participants and social connections is met and then progress takes a leap forward. There is no way to engineer getting to that threshold or even replicating it. Global sustainability may be the most important instance of emergence. We might have to all be doing all the right sustainable “things” and then, by some stroke of luck which we don’t understand, there could be a global paradigm shift and the condition of sustainability would emerge. If sustainability “emerges”, that means that there is no set mechanism that will guarantee that we get there. In these five descriptors, it will be necessary to document the different requirements that each stakeholder group brings to the project and maintain broad language that acknowledges contradictory values. This is important because the purpose of this evaluation is to re-evaluate approaches and goals. Remember that with most interesting and challenging environmental problems, we are in an infinite, iterative loop. There will never be a final report.

## 18.6 Engaging in the solution of environmental problems produces new knowledge

One of the major differences between traditional science and the transdisciplinary approach to science that we have adopted here is that our approach creates different types of knowledge that can't be reviewed and assessed very easily through peer review. A major strength of traditional science is that the peer review process is a robust mechanism for both improvement and building trust. However, environmental projects create many types of knowledge that may be inaccessible for anyone outside the project to assess. For example, a project that is restoring wetlands may develop and test hypotheses that lead to publications and presentations. These products can be peer reviewed. However, there is additional knowledge created by the wetland managers and the staff that did the restoration work. Some of this could be captured with written narratives of the processes, but some of it is tacit knowledge that allows the teams and team members to remove invasives and plant natives in just the right way. This leads to two major differences between "traditional" and what we call "mode 2" science (ref ***). First, the full team that is responsible for the project will be diffuse and ephemeral. The team needs to large and the membership flexible. The project is planned, carried out and then the team disperses to work on other projects. The people involved in the project are probably trained in a wide variety of disciplines, which complicates the analysis. Assessment of a successful project must include how well the members of the team worked together and whether the final "product" is illustrative of the team meeting its goals and objectives. The product is not just the written narrative or summative evaluation. The assessment of an unsuccessful project would be even more problematic. Is there evidence to determine that the reason for failure was based on unrealistic objectives, ineptly applied correct principles, effective application of the wrong principles or ineffective implementation? Although sorting this out would be very valuable, many failed projects seem to erode away with no clear statement of failure that would trigger an evaluation. Fortunately there are two important characteristics of a project that can be evaluated with "mode 2" scientific approach and can help establish a high degree of rigor and reliability.

Successful solutions will build the group's capabilities. The traditional conception of technology transfer is that information becomes available and is used in new instances. In Mode 2 science, the technology is transferred through the people who are involved. They learn information, techniques and skills that allow them to perform tasks and analysis required by for project. The "technology" is the human capital that develops, not specific knowledge products (such as publications) or machinery. The test of the quality of these capabilities is whether the participants join subsequent projects and contribute to other successful efforts. Thus, instead of judging the quality of a project by the production of a static and reliable publication (as in traditional science), quality is judged on the value added to a dynamic network by the diffusion of innovation.

Just as good traditional science has activities that are considered good practice, Mode 2 / transdisciplinary / project based science has characteristics that indicate good practice. In both cases, good practice is a necessary condition and does not guarantee high quality. There are three categories of good practice. First, there needs to be a high communication density. Information needs to flow back and forth between all of the participants and into each social and economic sector that is involved. The connections can be characterized using network descriptors. In particular, the structure of the communication network should have relatively high connectivity across the entire community, but there may be interesting brokerage and holes that help define information flow within the community. Another parameter that can be used to track the value of the network is "ascendency". This parameter is a measure of whether the right information got to the right person in a timely manner. High ascendency is desirable but requires infrastructure and investment in communication and social networks. Second, the number of sites where this approach is adopted indicates good practice. The participants with experience in best practices will use those in other venues and subsequent projects. Finally, tracking the diffusion of key innovations will demonstrate a valuable outcome of the originating project. These three qualities combined can be used to describe the quality of a project, i.e. it should have high communication density during the project, participants involved should use a similar approach in other successful projects, and key innovations should appear in subsequent successful projects.

## 18.7 Shift from accumulating knowledge to designing solutions

Transdisciplinary, problem-based science is similar to applied science or consultancy (Funtowicz and Ravetz ****). The focus is on the specific issue and its context. Solutions must have particular structures to deal with aspects of the problem, just as control systems need to have the same level of complexity as the system being controlled, the so-called Ashby's Law of Requisite Complexity. Therefore it is crucial to focus on the design of the solution and how all of the partners and their actions work together. There are approaches, such as the one EDA described in Chapter 1, that help identify the structure of knowledge and action. Applying design principles is particularly applicable to innovation and entrepreneurial solutions (see Chapters ** and **) because the entrepreneur is essentially attempting to remedy structural mismatches between resource allocation and the problem. Paul Polak provides a good example of focusing on design of a product and the context. He re-envisioned the cause of poverty as "people are poor because they don't make enough money" *** check actual quote *** (ref). His solution for rural farmers was to design a treadle-style footpump that would be able to irrigate shallow wells and provide enough water so that the farmer could grow enough excess produce to easily pay back the cost of the pump. This entrepreneurial approach provided a structural solution to poverty that worked in the context of sub-surface water, local produce markets and availability of human power. There have even been museum exhibits on all the human-scale designs that are aimed at “the other 90%” of the population who need clean water and extra produce more than they need an iPod (Smithsonian Institution 2007). Most of these designs work with existing components or components that can be fabricated locally to create sustainable solutions to the environmental and economic problems facing the world’s rural poor. The value is in the combination and the usefulness of that particular product. The quality control over the product is embedded in the community of users. The characteristics of these design processes can be assessed using the same Mode 2 science framework, because the products are put together from existing components but in a different fashion in each case.

## 18.8 Challenges for evaluation of complex environmental projects

Communication, the flow of information and the connection of meaning are essential for evaluating environmental projects. However, it can be extremely challenging to get people engaged in a discussion that centers around complexity and uncertainty. Often, they think it is too ill-defined  to be successful. The public may be underprepared to hear or deal with this message. As Wolfgang Sachs laments (ref ****) about American, how can we talk about sustainability when people are so busy trying to drive their cars a little bit faster of the freeways? There is also the temptation to leave complex questions to the technocrats who, in matters of public resource allocation, present a significant challenge to our democracies. Another source of resistance is the view that traditional science has been so successful in creating progress that we should not want to replace it with Mode 2 science. The response to this is that we are trying to provide for both traditional and Mode 2 when appropriate, which is a subtle distinction at best. To many it may seem as if Mode 2 science is just a cover for our inability as an environmental community to reach any consensus on how to deal with these complex socio-econo-environmental issues. It's difficult to argue with people who believe that there is a single objective and that we can arrive at an optimal solution if we just study the problem enough. They see the discussion of multiple possible viewpoints as an erosion of the objective approaches that have made so much headway in the last centuries. All of these challenges converge to form a situation in which organizations that employ the situational and transient nature of Mode 2 evaluative methods are unlikely to be backed up by the stable institutions that are currently successfully practicing traditional evaluations of quality (Gibbons et al. 1994). Even though these are substantial challenges, the main point is that Mode 2 / transdisciplinary scientific approaches can be used to reliably assess quality and reliability, and that these evaluations will be extremely useful to all parties involved. These modern scientific methods bring the dimension of value and judgment into the process in a rigorous manner.

## 18.9 Summary

Ongoing evaluation is a critical element in any enterprise. A scientific evaluation must be systematic, rigorous, based on evidence and verifiable. Dealing with "wicked problems" requires a level of community stakeholder involvement, a commitment to allowing values to be incorporated into management from the beginning, and a respect for the inherent uncertainty of any specific outcomes. These characteristics undermine the utility of the traditional scientific modes for evaluating quality. This is bad because traditional science is such a powerful mode of addressing many problems. Mode 2 science is an appropriate approach for transdisciplinary issues and is probably the best method for dealing with wicked problems because it includes the value dimension.

Mode 2 involves evaluation of the new forms of knowledge that have been gained by members of the community (not just scientists) and assesses how these people use their newly acquired capabilities to solve the current problem and how they disseminate and employ these capabilities in subsequent projects. One major strength of traditional science is that the quality of freestanding, timeless knowledge products is judged through stringent peer review. While these products are very valuable to science in general, Mode 2 science instead focuses on the ephemeral increase in capacity to solve the problems. Individual problems need one-of-a-kind approaches, not standard methods.

Probably the major challenge to adopting Mode 2 approaches is that people feel that the success of traditional science can be extended to cover these situations. However, in attempting to extend traditional science to meet these needs, they use a narrow definition of objectivity that reduces the importance of incorporating values and essentially casts the entire evaluation onto a single dimension. As with all of the intellectual tools presented in this text, more use of the approach leads to improved skills at dealing with the problem and better outcomes. It may take more practice and experience to be able to effectively employ this approach on wicked problems with enough expertise to outperform the more tried-and-true traditional evaluative techniques.

Integrative Approaches

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http://web.pdx.edu/~rueterj/ia/